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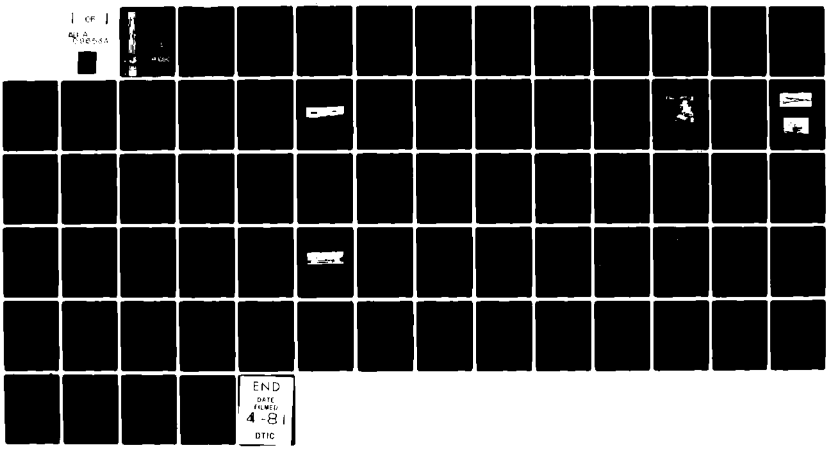

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EVALUATION OF VIBRATORY ROLLERS FOR BOMB DAMAGE REPAIR

KENNETH J. KNOX
ENGINEERING RESEARCH DIVISION

AUGUST 1980

FINAL REPORT
OCTOBER 1978 - SEPTEMBER 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Four vibratory rollers in the 8.5 to 17-ton range were evaluated for use in bomb damage repair of airfields. The rollers were tested for their compaction ability on graded crushed limestone. After this initial testing the two most promising rollers were tested by repairing simulated bomb craters using 24-inch thick layers of crushed limestone compacted only from the surface. These repairs were tested with F-4 loadcart traffic. Despite difficulties in predicting roller performance, 10-ton vibratory rollers or heavier are capable of compacting crushed limestone from the surface only to support F-4 loads.

394633

PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall AFB, Florida, under Job Order Number 20546B01 Bomb Damage Repair Compaction Study. Data from this test resulted in recommendations to purchase vibratory rollers for the Air Force Bomb Damage Repair kits. Further research in crushed limestone repairs compacted with vibratory rollers was also undertaken. This work was accomplished during the period from October 1978 to September 1979.

This report discusses the use of vibratory rollers in bomb damage repair. The report does not constitute an indorsement or rejection of any specific roller for Air Force use nor can it be used for advertising a product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

KENNETH J. KNOX, 1Lt, USAF
Project Officer

ROBERT E. BOYER, Lt Col, USAF
Chief, Engineering Research Division

FRANCIS B. CROWLEY, III, Col, USAF
Director, Engineering and Services Laboratory

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SECTION I

INTRODUCTION

BACKGROUND

High performance military aircraft depend on a high quality pavement for launch and recovery operations. This dependency makes the airfield a prime target for enemy attack. Consequently, the rapid repair of weapon-damaged runways is a capability critical to the prompt response required following an airbase attack. This urgent requirement has led to the Rapid Runway Repair (RRR) research and development program of the Air Force Engineering and Services Center (AFESC), Tyndall AFB, Florida.

Prior research in Rapid Runway Repair (RRR) has identified three items pertinent to this study (Reference 1). The first item is the importance of compaction to an expedient repair. With the possible exception of certain structural caps, expedient pavement repairs must be adequately compacted to prevent consolidation and patch failure. The second item is concerned with compaction equipment. Field tests conducted by AFESC at the Tyndall AFB Small Crater Test Facility have demonstrated that current RRR compaction equipment is inadequate to provide proper compaction for repairs without some type of structural cap (i.e., AM-2 mat). The third item of research pertinent to this report is the promising performance of crushed stone (base course) as an expedient RRR material. When adequately compacted, a 24-inch layer of unsurfaced crushed stone is capable of carrying F-4 aircraft wheel loads. The problem with this repair method is again with the compaction. As mentioned above, current RRR compaction equipment is inadequate due to the large number of layers required and the consequently great amount of time required for compaction.

In order for crushed stone to be feasible as a Rapid Runway Repair material, a rapid method of compaction is required. Ideally this compaction would be applied at the surface only of a single layer of material. With this in mind, an in-house literature search of compaction was undertaken. The results of this search indicated that heavy vibratory rollers would have the best chance of adequately compacting crushed stone to a depth of 24 inches or more.

OBJECTIVE

The objective of this testing program was to evaluate the performance of heavy vibratory rollers for use in the rapid repair of weapon-damaged airfield pavements. This information will be used to determine specifications for compaction equipment needed to upgrade the Air Force Rapid Runway Repair kits at overseas bases. The information from this study will also be used to evaluate the use of unsurfaced compacted aggregate for expedient pavement repairs.

APPROACH

Field tests and analysis were conducted to meet the objective of this testing program. Self-propelled vibratory rollers with varying characteristics (drum weight, dynamic force, frequency, and amplitude) were used to compact various layer thicknesses of base course material. The parameters that were monitored were:

1. Material density.
2. Material moisture content.
3. Roller drum weight.
4. Roller dynamic force.
5. Roller frequency.

Based on the results of this initial testing, the most promising rollers were used to make simulated crater repairs using the base course material. These repairs were evaluated with F-4 loadcart trafficking.

At the conclusion of the testing, the U. S. Army Engineer Waterways Experiment Station (WES) performed a literature search, reviewed the data collected, and assisted in data analysis.

SECTION II

DESCRIPTION OF TESTS

TEST AREAS

The field tests were conducted at the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida. The initial roller evaluation tests were conducted under shelter in a specially-prepared test pit. The F-4 loadcart tests were conducted at the Small Crater Test Facility at Tyndall Air Force Base.

For the initial roller evaluation tests, two 7-foot-wide by 45-foot long test lanes were constructed, separated by a 7-foot-wide buffer lane. Each 45-foot-long test lane was divided into three 15-foot test items, which contained crushed limestone at three different moisture contents. Each lane had a 15-inch lift of crushed stone placed on top of a well-compacted crushed stone base. Figure 1 shows a plan and profile of the test section.

One deep lift test was conducted, in which the performances of the lightest and heaviest rollers were compared. The above test section was dug out to a depth of 40 inches, and the two 45-foot long test lanes were divided into two 22.5-foot test items (Figure 2).

The Small Crater Test Facility, location of the F-4 loadcart trafficking tests, was constructed to allow accelerated traffic tests of various pavement repair materials and designs. A clay core 60 feet wide, 220 feet long, and 6 feet deep was placed and compacted at a high water content to provide a weak test subgrade. Twelve inches of crushed limestone were used as a base course, followed by a 10-inch-thick portland cement concrete pavement. Three 20-foot by 20-foot-square sections were left open in the concrete to serve as test pits. The local dune sand was stabilized with oyster shells to construct a sand fill around the test site. Figures 3 and 4 provide plan and cross section views of the test site.

The 20-foot-square test pits provided a location to construct representative pavement repairs. The depth to the clay subgrade can be varied by adding or removing clay as necessary. Following traffic on any test repair, the repair materials can be removed and a different repair constructed in the same pit. For these series of tests, the depth to the clay subgrade was maintained at 24 inches.

VIBRATORY ROLLERS

Based on a literature search which preceded this effort, it was determined that heavy self-propelled vibratory rollers (drum

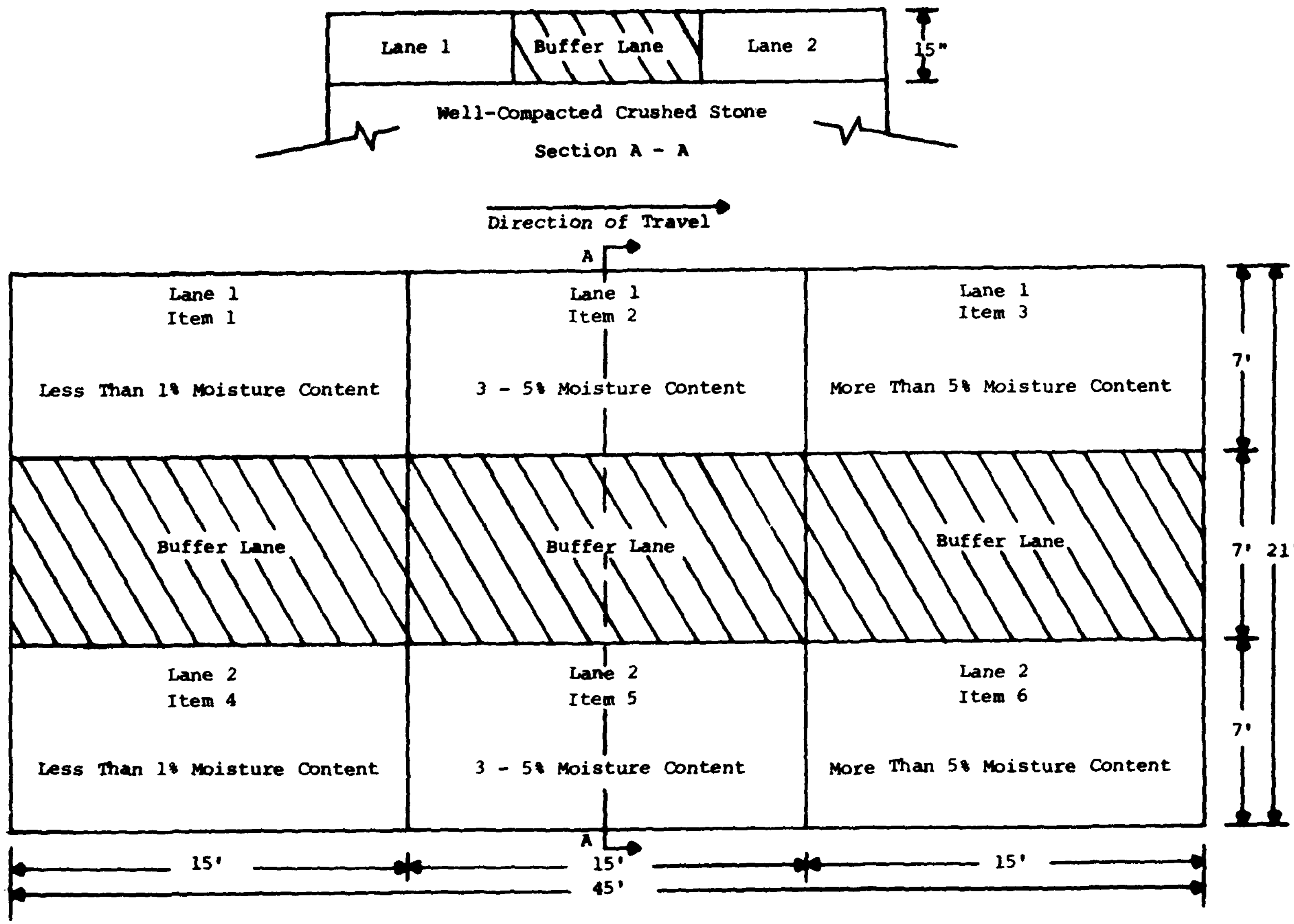

Figure 1. Typical Roller Evaluation Test Section

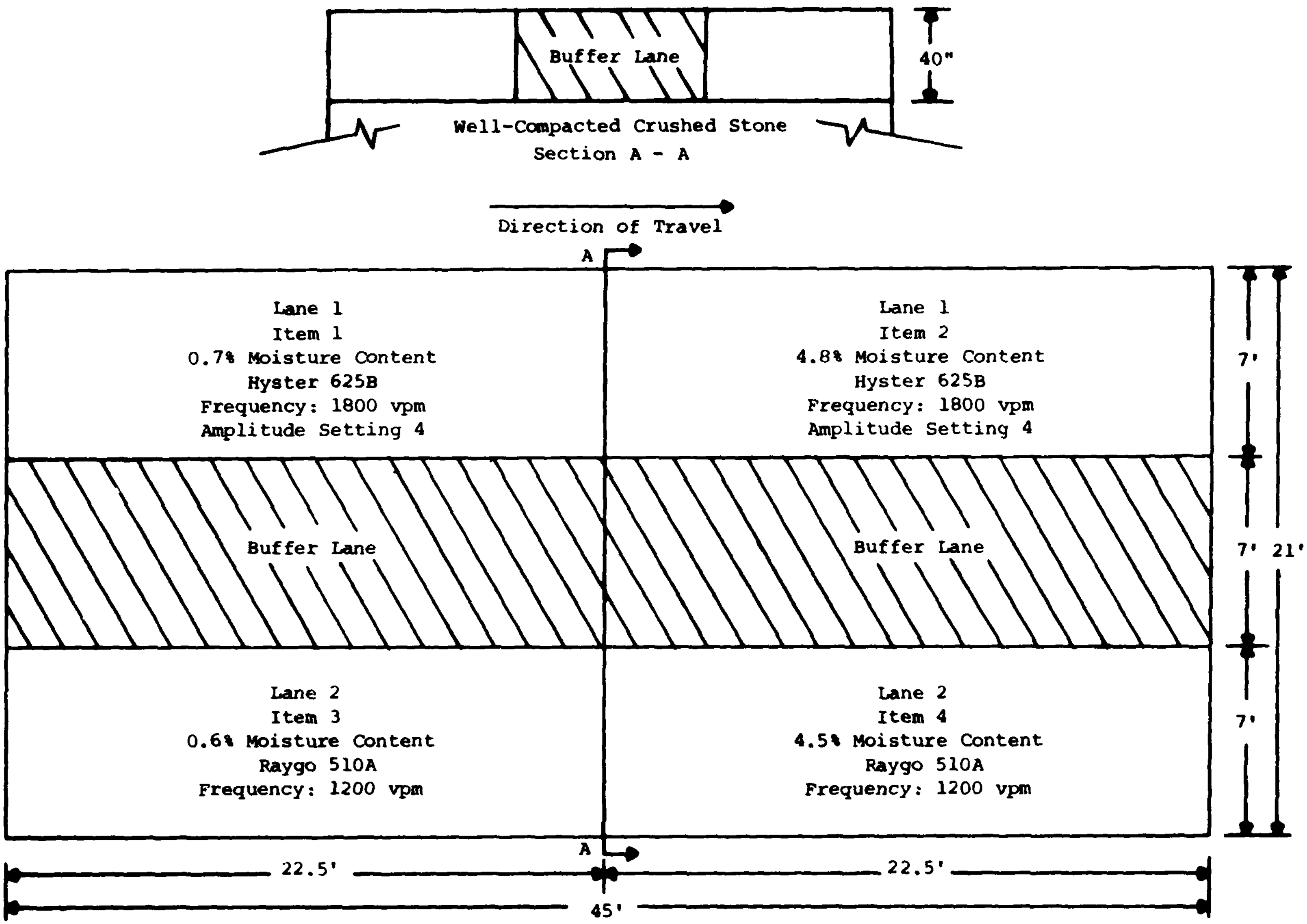

Figure 2. Deep Lift Test Section

weights in excess of 8000 pounds) may be able to adequately compact 2- to 3-foot layers of base course material in order to carry tactical aircraft loads. As a result of this study, selection of the four vibratory rollers tested in this compaction study was based primarily on their static drum weights. The Hyster 625B vibratory roller was also selected for its wide range of frequency and amplitude settings. This roller was extensively used to study the effects of varying frequency and amplitude (and consequently dynamic force, which is a function of frequency and amplitude) in the compaction of crushed stone. The rollers are shown in Figure 5, and the characteristics of the vibratory rollers are listed in Table 1.

SOILS

The initial roller evaluation tests employed a 1-inch-minus crushed limestone with the following characteristics:

Gradation: See Figure 6
Specific Gravity = 2.81
Liquid Limit = Non-plastic
Plasticity Index = Non-plastic
Unified Soil Classification = SP-SM
Maximum Dry Density (Modified AASHO) = 146.0 pcf
Optimum Moisture Content = 5.5%

The moisture-density relationship was determined in accordance with the modified AASHO compaction control test (Reference 2).

The F-4 loadcart trafficking tests employed a 1½-inch-minus crushed limestone with the following characteristics:

Gradation: See Figure 7
Specific Gravity = 2.76
Liquid Limit = Non-plastic
Plasticity Index = Non-plastic
Unified Soil Classification = SP-SM
Maximum Dry Density (Modified AASHO) = 147.2 pcf
Optimum Moisture Content = 5.7%

The laboratory compaction curves for both crushed limestones typically showed a high dry density at zero moisture content, a reduction in dry density as moisture content increased to 2 to 3 percent, and then an increase in maximum dry density with increasing moisture content. The compaction curve flattened out near the maximum dry density, at which time free water also began seeping out of the compaction samples. Such double-peaked curves are considered typical of cohesionless sandy soils (Reference 3) and have also been observed in the past for crushed limestone (Reference 4).

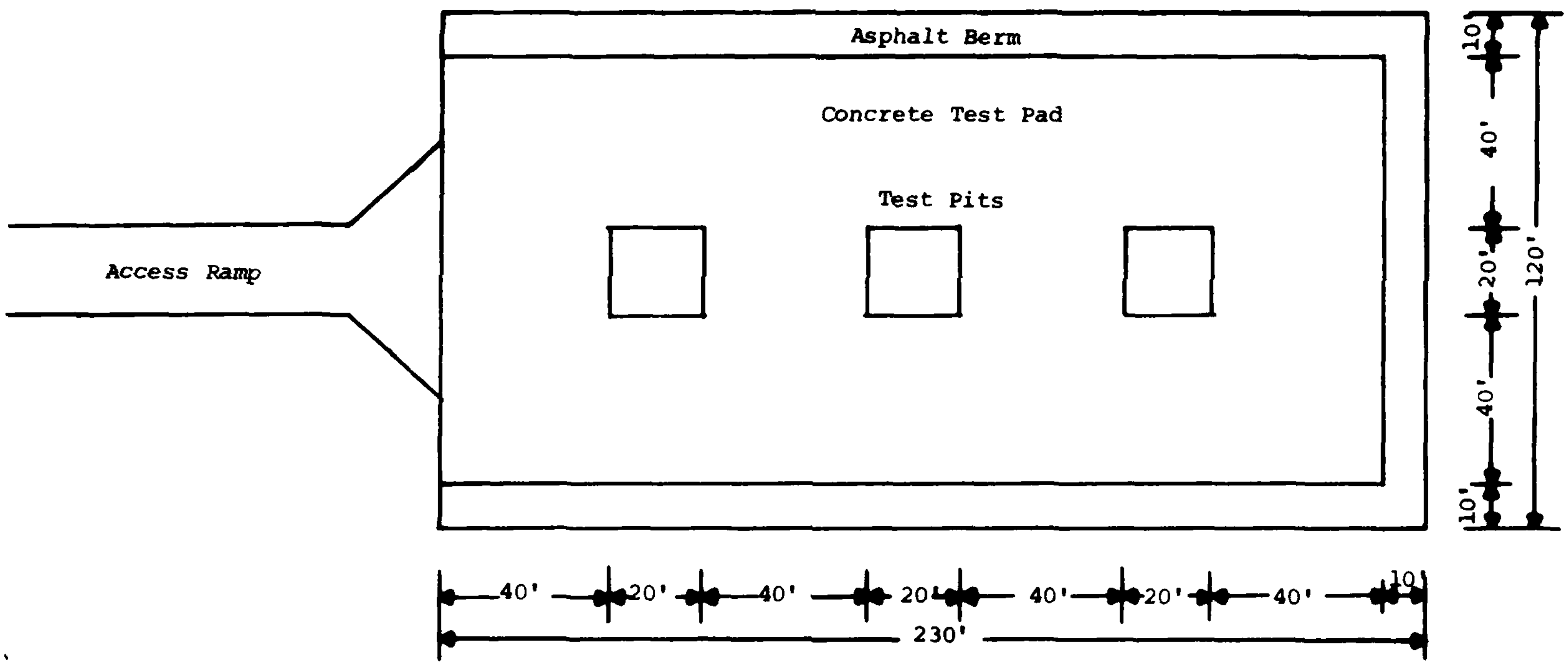

Figure 3. Plan View of Test Site

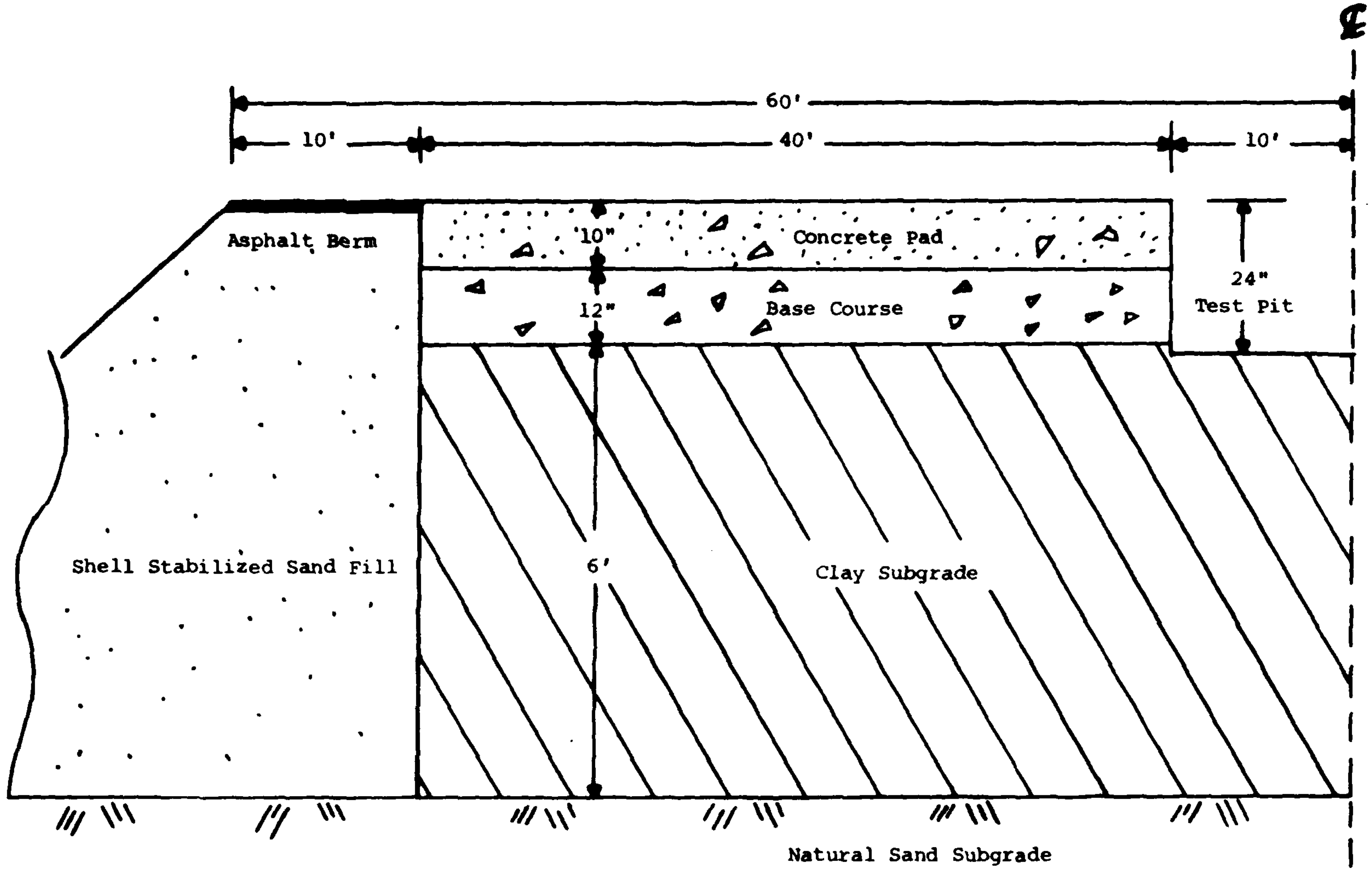

Figure 4. Test Pad Cross Section

Figure 5. RayGo 510A, Hyster 625B, RayGo 400A and RayGo 404B Vibratory Rollers

Table 1. Vibratory Roller Characteristics

Roller	Machine Shipping Weight lbs	Drum Weight lbs (Estimate)	Rated Dynamic Force, lbs (Generated at Maximum Frequency Unless Otherwise Noted)	Weight per Lineal Inch of Drum Width, lbs (Estimate)	Frequency Range, VPM	Number of Amplitude Settings	Drum Diameter, Inches	Drum Width, Inches
Raygo 404B	17,080	8,540	27,000	102	1200-2300	2	59	84
Hyster 625B	17,000	9,180	25,000	109	1200-2400	4	47.5	84
Raygo 400A	20,000	11,000	27,000	131	1100-1500	1	59	84
Raygo 510A	33,500	18,425	45,000	230	1100-1500	1	60	80

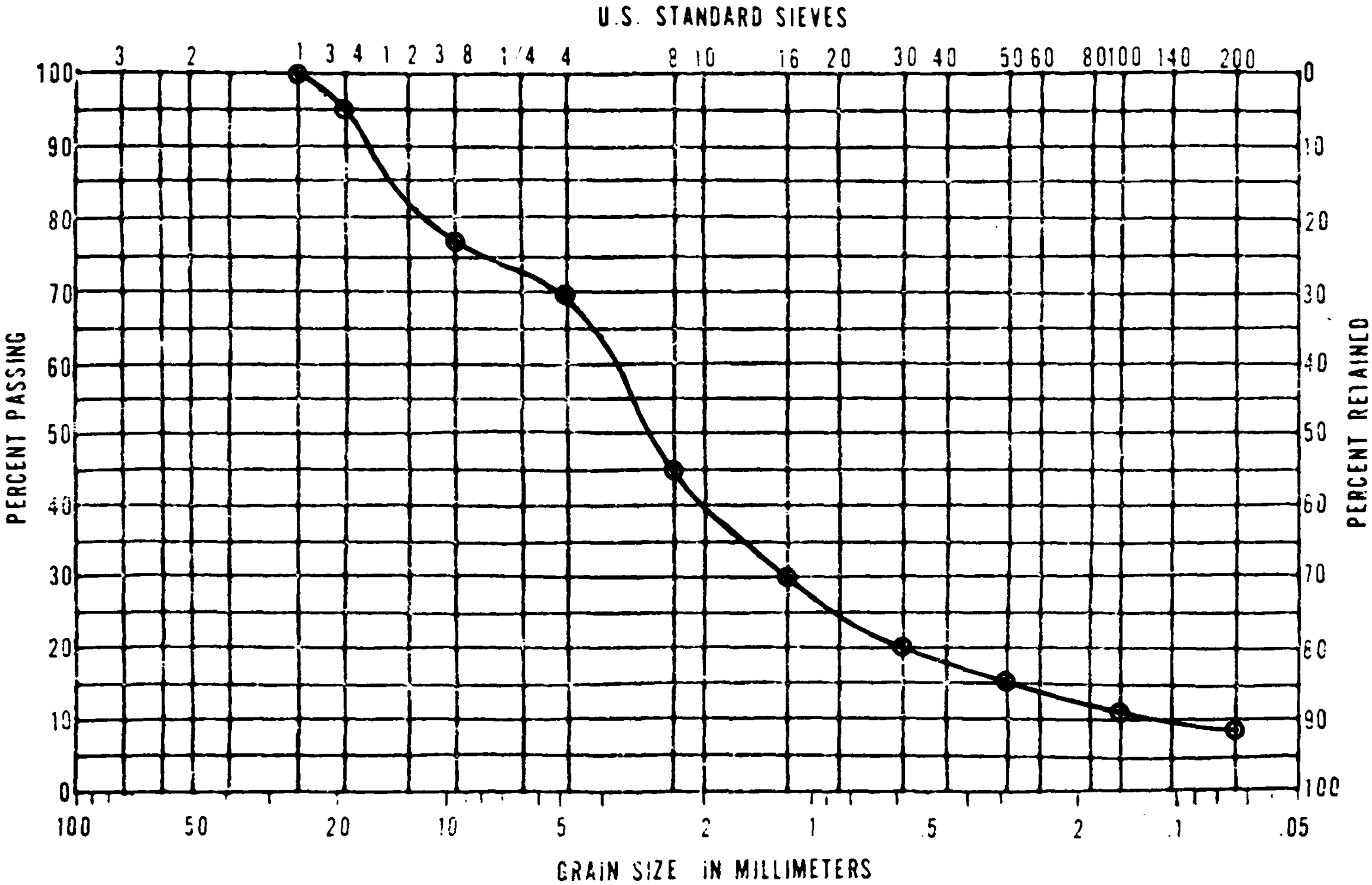

Figure 6. Gradation of 1" Crushed Limestone

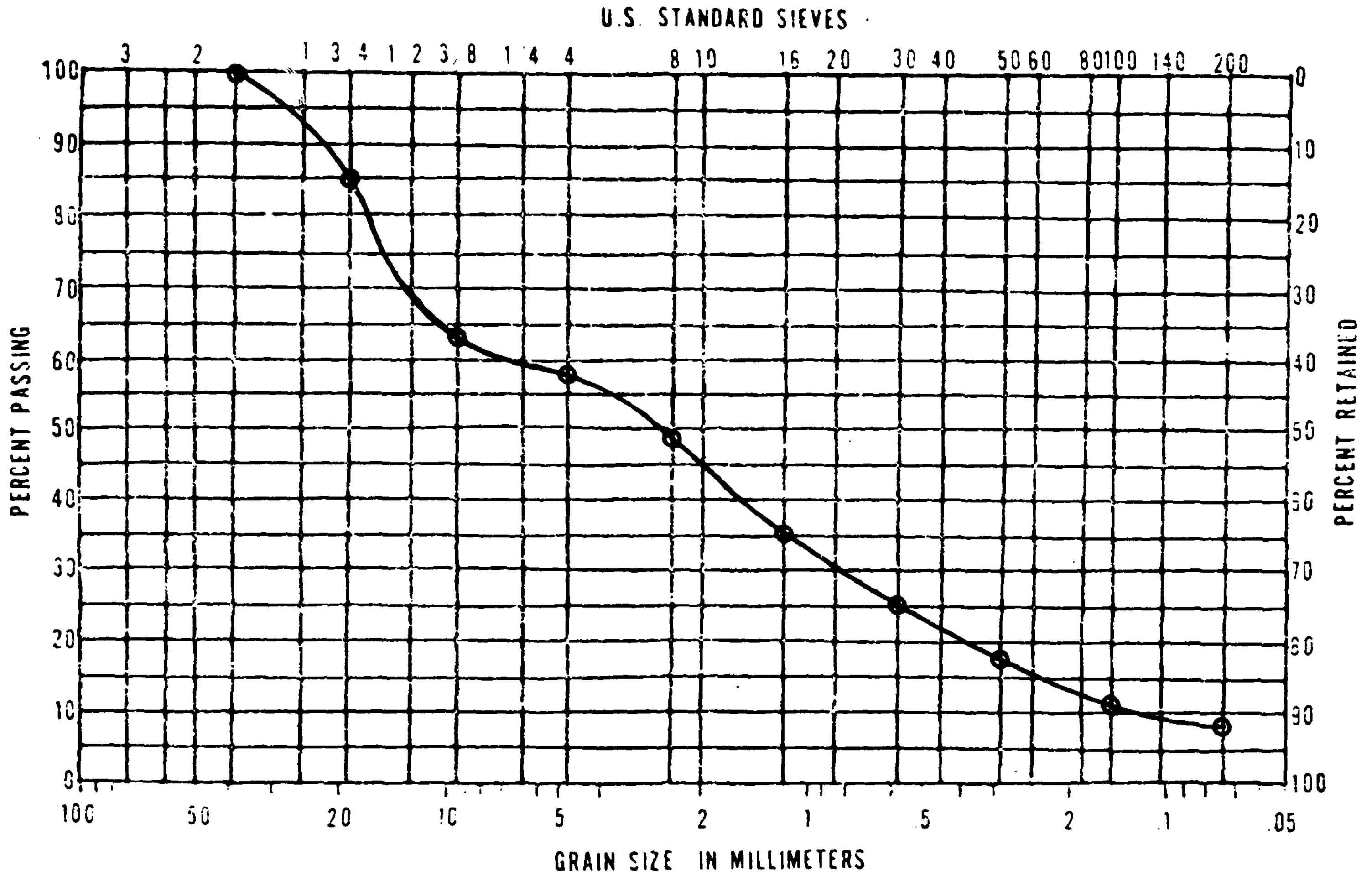

Figure 7. Gradation of 1½" Crushed Limestone

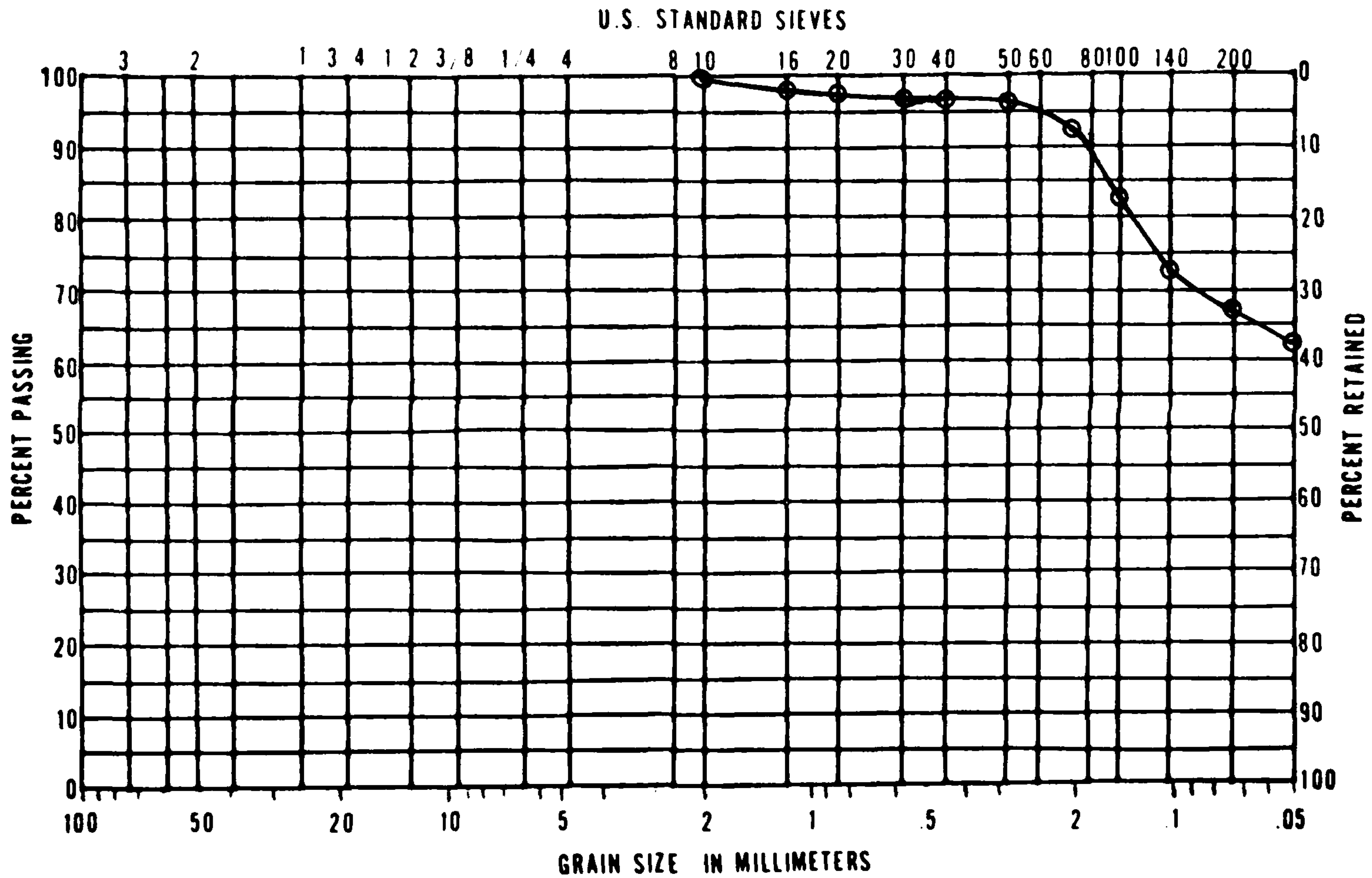

Figure 8. Gradation of Wewahitchka Clay

The clay used for the traffic test subgrade was a local clay obtained near Wewahitchka, Florida. This clay was placed at an average moisture content of 27 percent and a California Bearing Ratio (CBR) of 4. This strength was selected as a representative lower bound for crater debris backfill based on eight previous crater repair field tests (Reference 5). The clay had the following characteristics:

Gradation: See Figure 8
Specific Gravity = 2.61
Liquid Limit = 65%
Plasticity Index = 41%
Unified Soil Classification = CH
Maximum Dry Density (Modified AASHO) = 113 pcf
Optimum Moisture Content = 14.5%

NUCLEAR MOISTURE-DENSITY TESTING

All field density and moisture measurements were made with a Troxler 3411B nuclear moisture-density gauge (Figure 9). Past research has shown that the accuracy to be expected from nuclear gauges is at least as good as conventional field methods, such as the sand cone or water balloon methods (Reference 6). A moisture correction factor was calculated for the nuclear gauge using oven-dried moisture samples, and dry densities were calculated using the corrected moisture contents.

Density measurements were made with the radioactive probe set at 4, 8, and 12 inches. In general, the average densities from these three depths did not vary significantly from one another, so the data analysis used only the 12-inch-depth densities. This represents the average density of the material between the probe (source) at 12 inches and the sensor on the surface.

Figure 9. Troxler 3411B Nuclear Moisture-Density Gauge

SECTION III

FIELD TESTS

INITIAL ROLLER EVALUATION TESTS

Soil Preparation and Placement

The 1 inch crushed limestone to be tested was spread out on an asphalt mixing pad and either allowed to dry or water was added in order to obtain the desired moisture content (Figure 10). The desired moisture contents were 0.0, 4.0, and 5.5 percent. The moisture contents actually obtained ranged from 0.2 to 0.9 percent, 3.8 to 4.9 percent, and 4.9 to 7.7 percent. These variations reflect the difficulty of controlling moisture content, particularly at high levels, in free-draining soils. The mositure content of test items often decreased between the beginning and the end of the test. In all following discussion, the moisture content of a test item is defined as the moisture content at the beginning of the test. Next the stone was carefully mixed to insure uniformity of moisture, and then placed in the 15 inch deep test pit. Figure 11 shows an International Harvester TD-7 dozer with high-flotation tracks leveling the test section prior to the start of testing.

Compaction

Two roller settings were tested simultaneously, one in Lane 1 and one in Lane 2 of the test section. A total of 18 roller settings were tested, which provided 52 individual test items. These settings are given in Table 2. Nuclear moisture and density measurements were generally made after 0, 1, 2, 3, 4, 5, 6, 8, 10, 14, 18, 24, and 36 passes of the roller. Test sites were located near the center of each test item in such a way that no two measurements were made at the same location in order to minimize interference from previous probe holes.

The vibratory rollers were all operated at similar machine settings that would allow comparison among the machines. This information would hopefully yield data on the effects of static weight on the compaction of crushed limestone.

The effects of frequency and dynamic force changes on the compaction of crushed limestone were studied using the Hyster 625B vibratory roller. Frequency data was generated by holding the amplitude constant (at setting #2) and changing the frequency in increments of 300 vibrations per minute (vpm) from 1200 to 2400 vpm. Data on the effects of dynamic force changes was generated by holding the frequency constant at 1800 vpm and performing compaction tests at the four amplitude settings that were available on the Hyster 625B.

Figure 10. Adjusting the Moisture Content of the Crushed Limestone

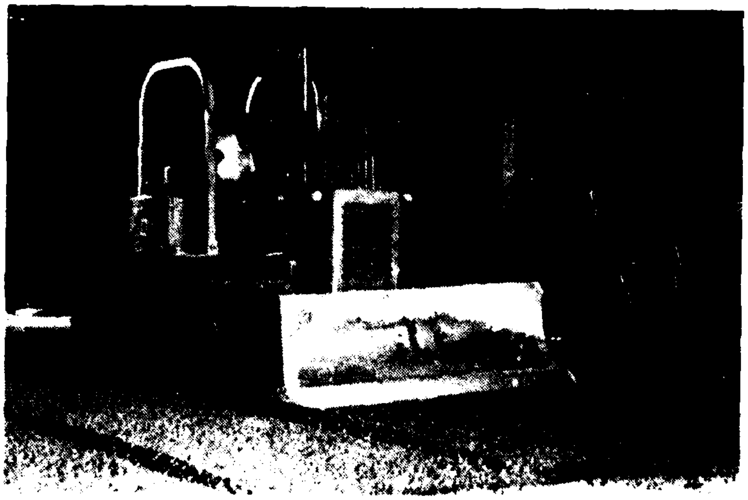

Figure 11. Leveling the Crushed Limestone Prior to Testing

TABLE 2

VIBRATORY ROLLER SETTINGS

MACHINE	FREQUENCY, VPM	AMPLITUDE SETTING	DYNAMIC FORCE, POUNDS	MOISTURE CONTENTS, PERCENT
Hyster 625B	1200	2	5000	0.5, 3.8, 6.4
	1200	4	9500	0.6, 4.7, 5.7
	1200	4	9500	2.6, 3.1 *
	1500	2	9000	0.3, 4.0, 6.1
	1800	1	7000	0.6, 4.3, 5.4
	1800	2	13500	0.8, 4.1, 5.1
	1800	3	19500	0.7, 4.0, 4.9
	1800	4	25000	0.5, 3.7, 5.0
	2100	2	18000	0.8, 4.1, 5.9
	2400	2	23500	0.5, 4.6, 5.4
RayGo 404B	1200	HI	13500	0.6, 4.6, 7.7
	1700	HI	27000	0.6, 4.4, 5.9
	2300	LO	27000	0.4, 4.9, 5.5
RayGo 400A	1200	--	17500	0.5, 5.1, 5.9
	1500	--	27000	0.6, 4.4, 5.7
RayGo 510A	1200	--	29000	0.4, 5.3, 6.8
	1200	--	29000	2.8, 3.2 *
	1500	--	45000	0.7, 4.7, 6.5

* These test items were used to generate a moisture-density relationship for the roller.

Data Analysis

Frequency - When the frequency of forced vibrations of a vibrator coincide with the natural or resonant freqency of the system, the amplitude of the displacements reach a maximum. There have been numerous attempts to compact soils at their natural frequency to take advantage of this phenomenon.

Unfortunately, the natural frequency of soils is a variable and not a unique constant value. The natural frequency is affected by the type of soil, its density and moisture content, the roller's weight, the generated dynamic force, and the stiffness and damping characteristics of the system. Since a unique resonant frequency does not exist for soils, it is necessary to consider resonance as a characteristic of a specific soil-roller system rather than an index property of the soil. This makes it impractical to rely on vibratory compaction in the field occurring at the natural frequency.

Effective compaction can occur at frequencies other than those causing resonance in the soil-roller system. Early investigators of vibratory compaction generally agree that frequency is a key parameter; however, no consistent recommendation on the selection of frequency has come from these earlier studies. A recent study by Yoo and Selig on vibratory compaction (Reference 7) uses a two-degree-of-freedom model which is backed up by field testing. This study predicts that drum displacements have two natural frequencies: one mainly affected by the frame characteristics and the other affected mostly by the drum. For increasing frequencies above those two natural frequencies (which is the normal range of operation) the drum displacement gradually decreases.

Frequency data for this study was obtained using the Hyster 625B roller due to its wide range of frequency. Figures 12 through 14 show the increase in density with increasing compaction for crushed limestone at dry, medium, and high moisture contents, respectively. These three figures show that, as the moisture content increases, the density variations associated with varying frequencies become smaller. Specifically, the dry density at 36 coverages of the roller varied by 4.9 percent for dry moisture contents, 2.9 percent for medium moisture contents, and 2.2 percent for high moisture contents.

The fact that frequency of a vibratory roller affects the soil density has been well established by previous investigators and is borne out in Figure 15, the data of which comes from Figures 12 through 14. However, these investigators' recommended frequency for best compaction has varied from the resonant frequency to the range of 0.5 to 2.5 times the resonant frequency to the highest possible frequency (References 8 and 9). An examination of Figure 15 shows that it is not possible to provide a simple rule to explain the effect of frequency. With the current

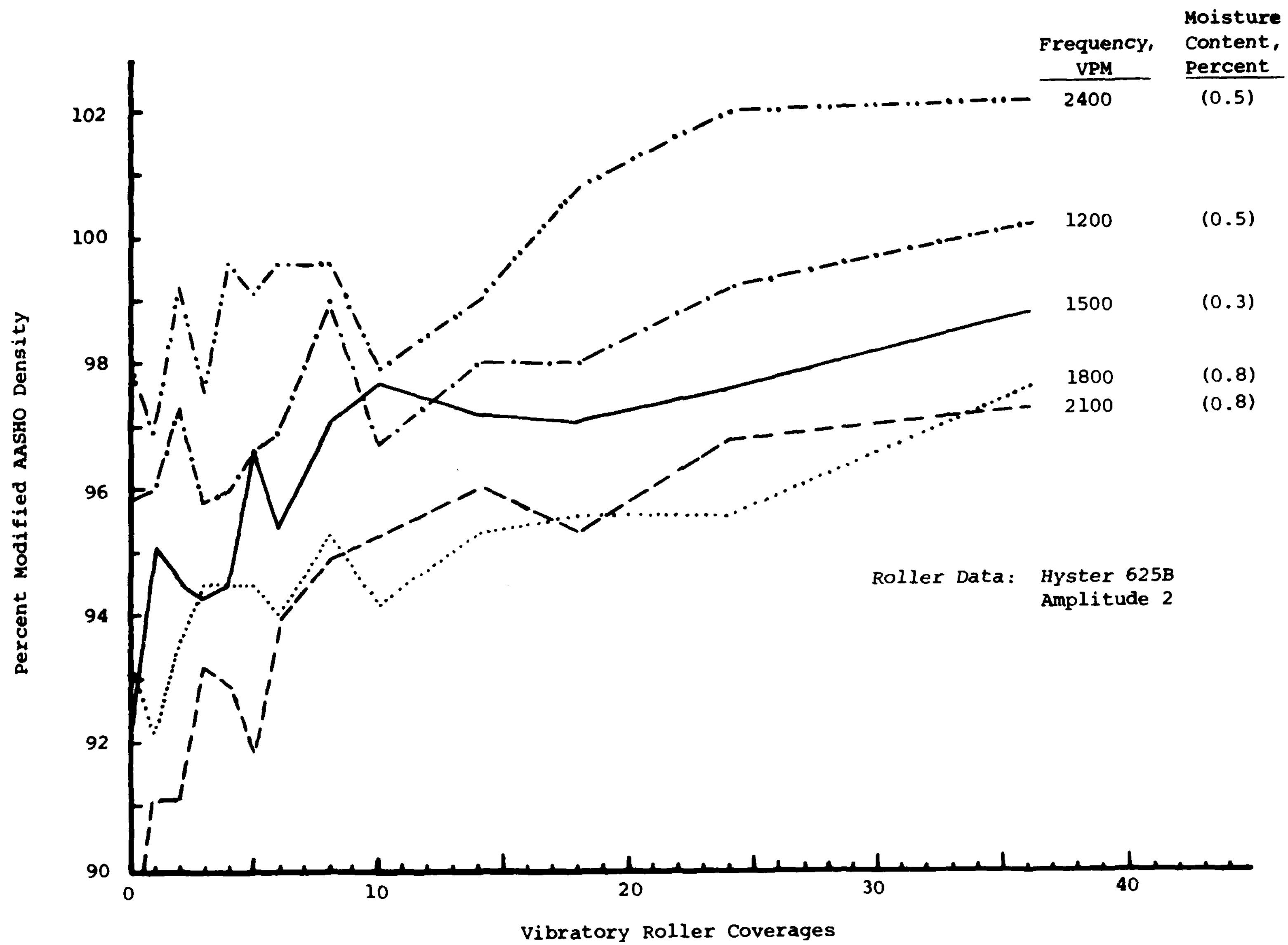

Figure 12. Effect of Frequency at Dry Moisture Contents

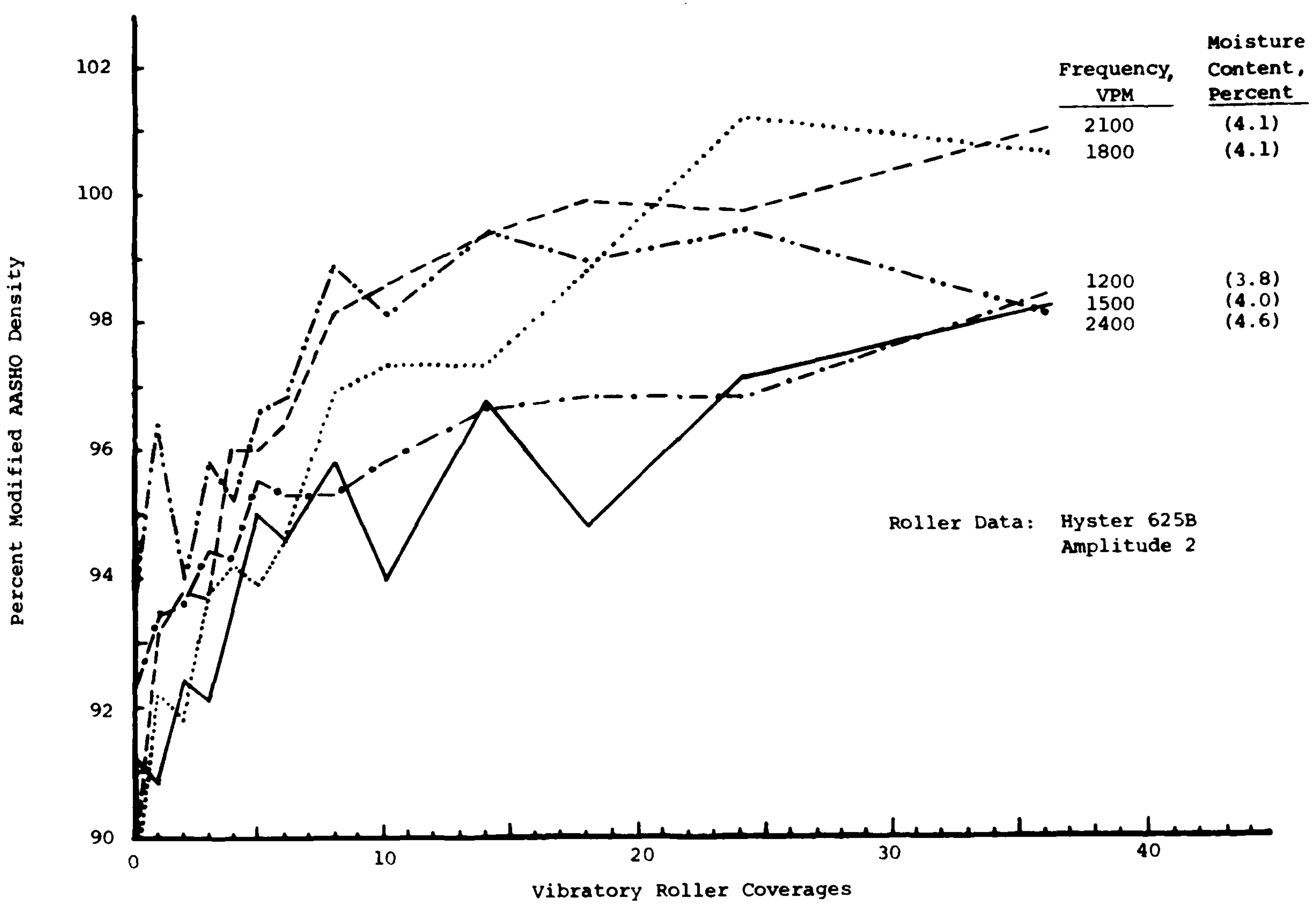

Figure 13. Effect of Frequency at Medium Moisture Contents

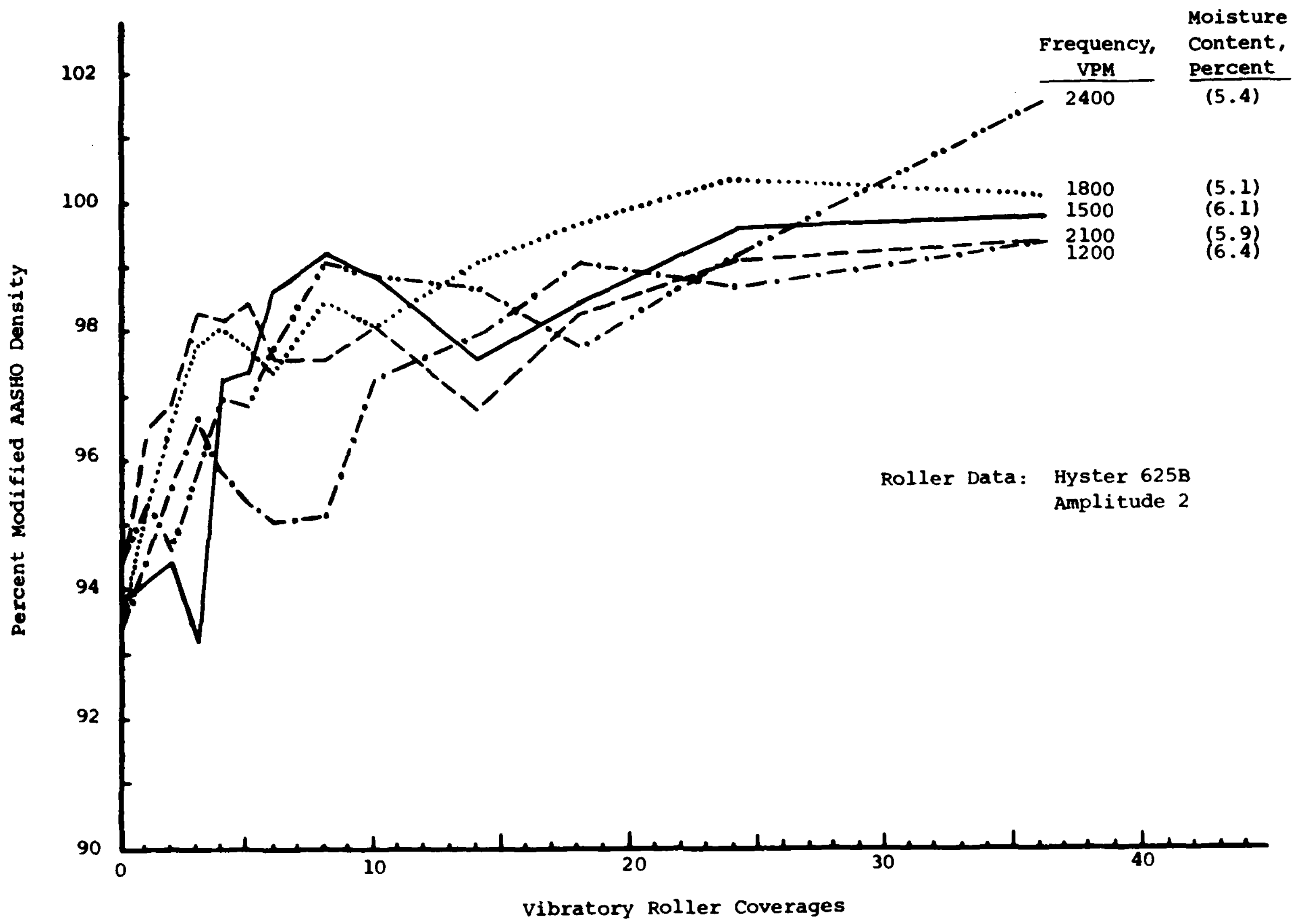

Figure 14. Effect of Frequency at High Moisture Contents

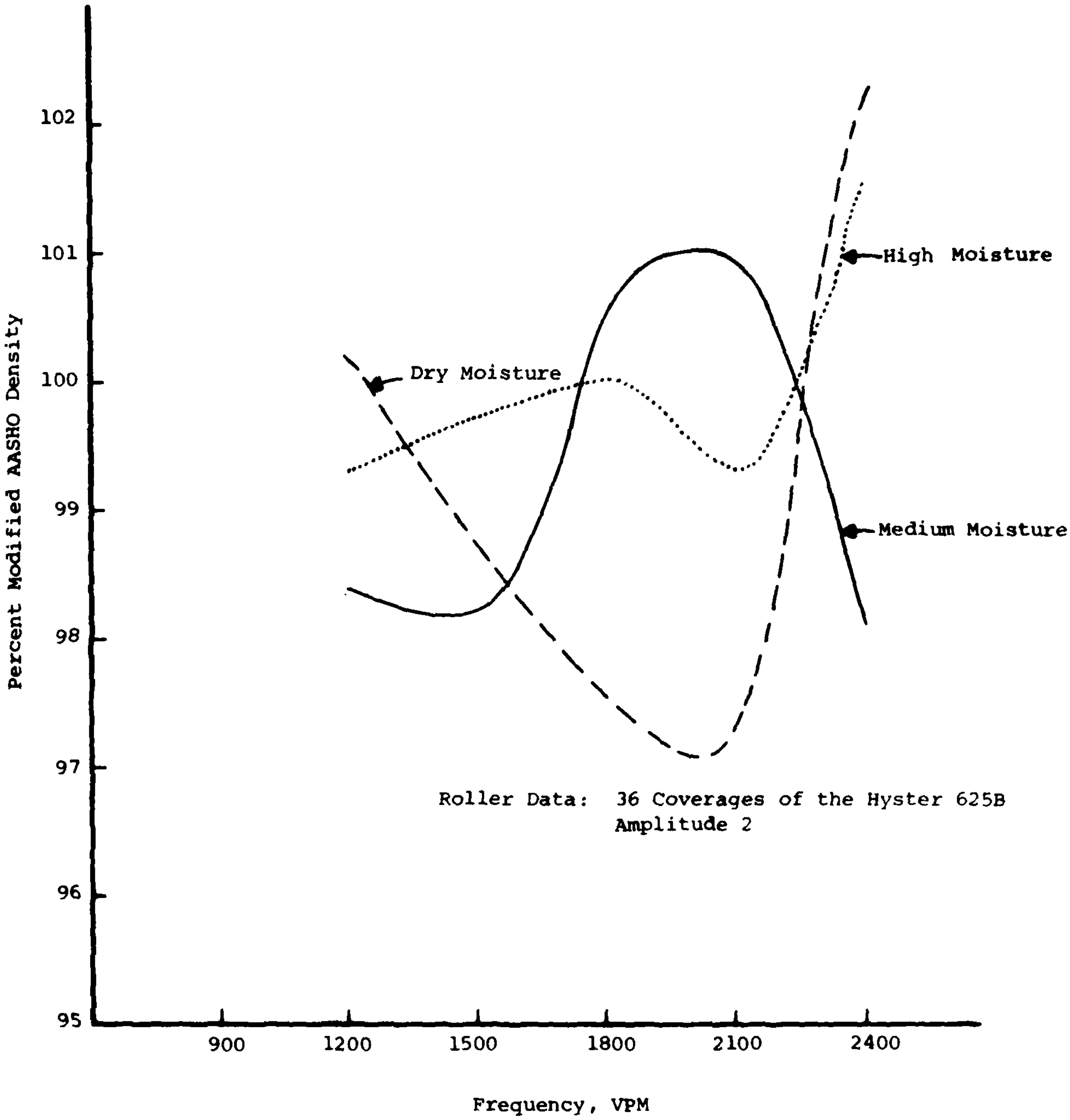

Figure 15. Effect of Frequency

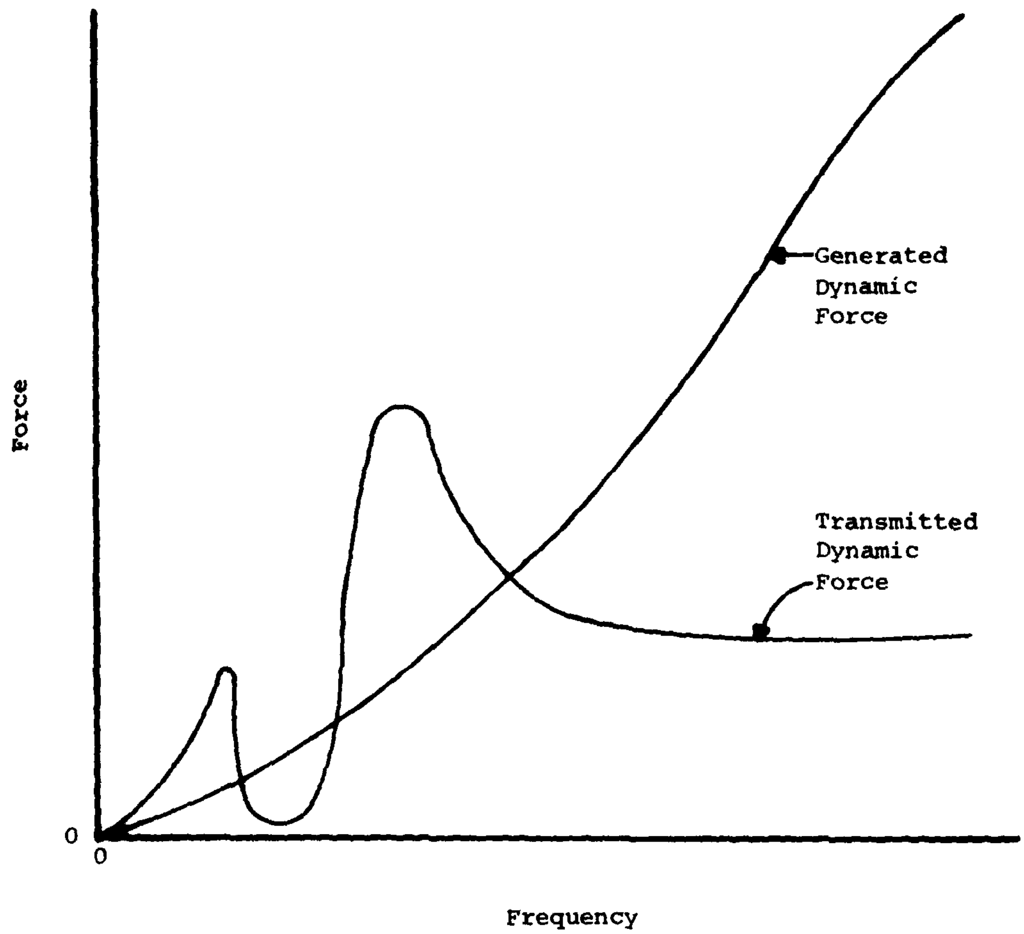

Figure 16. Comparison of Generated and Transmitted Dynamic Force

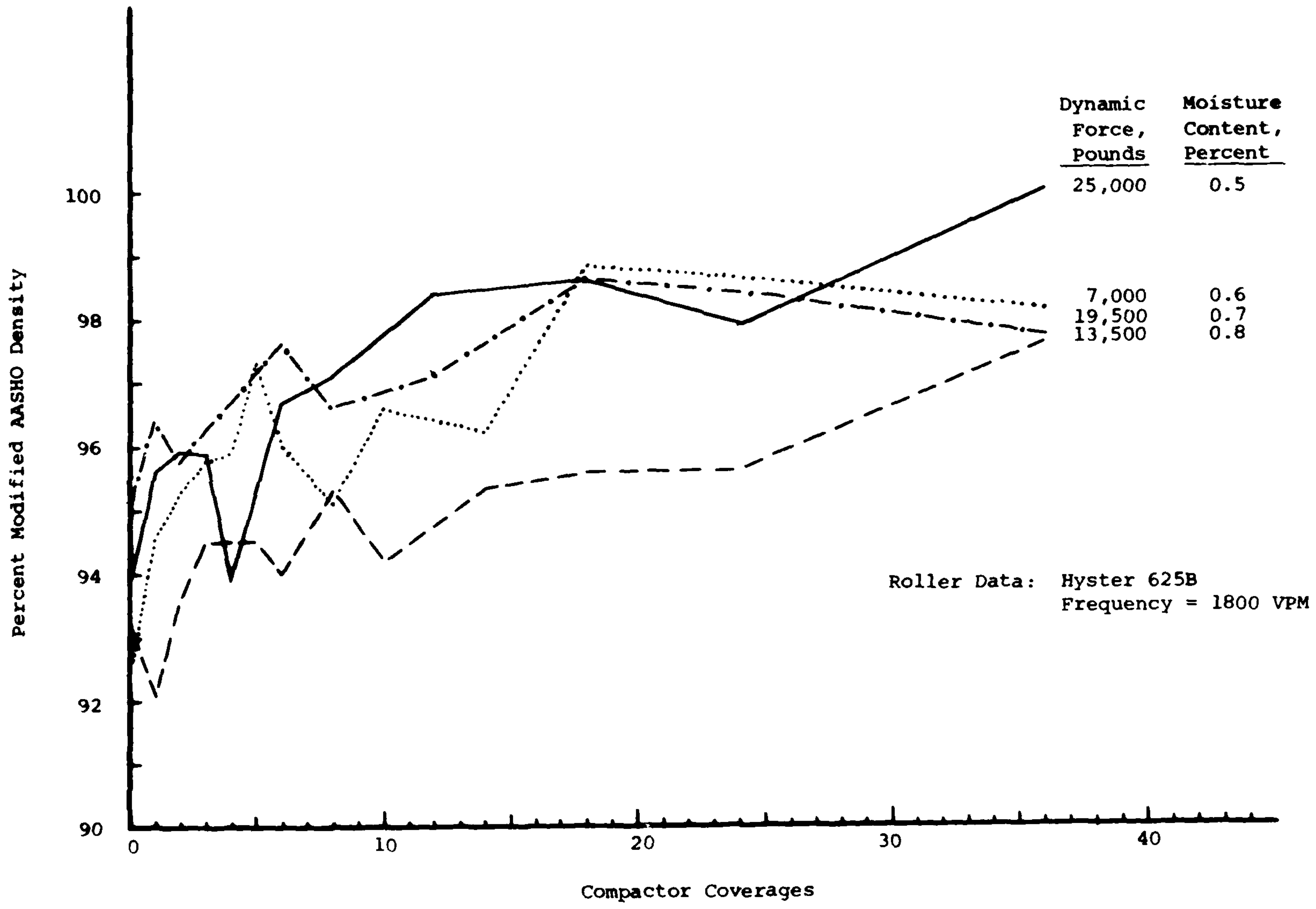

Figure 17. Effect of Dynamic Force at Dry Moisture Contents

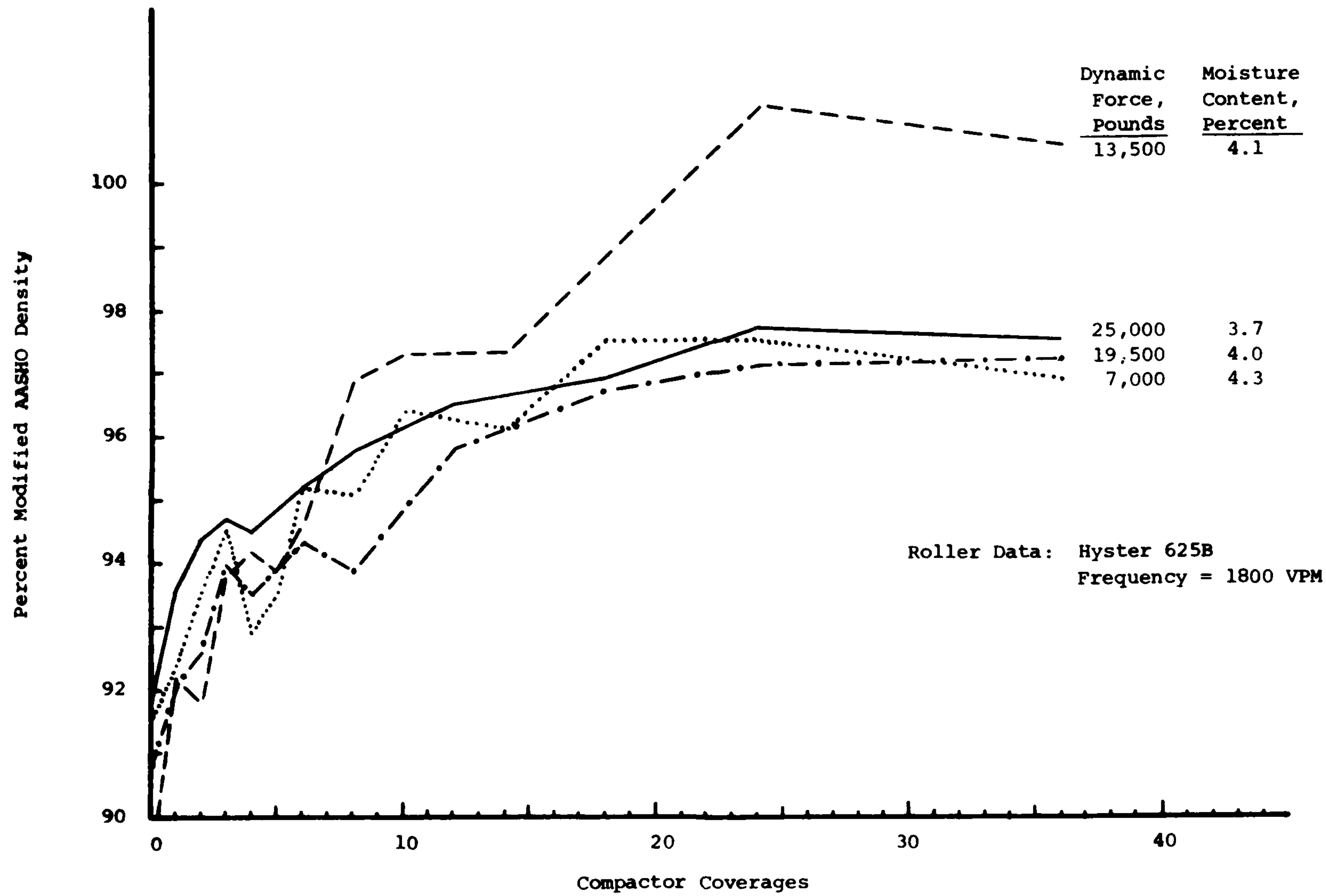

Figure 18. Effect of Dynamic Force at Medium Moisture Contents

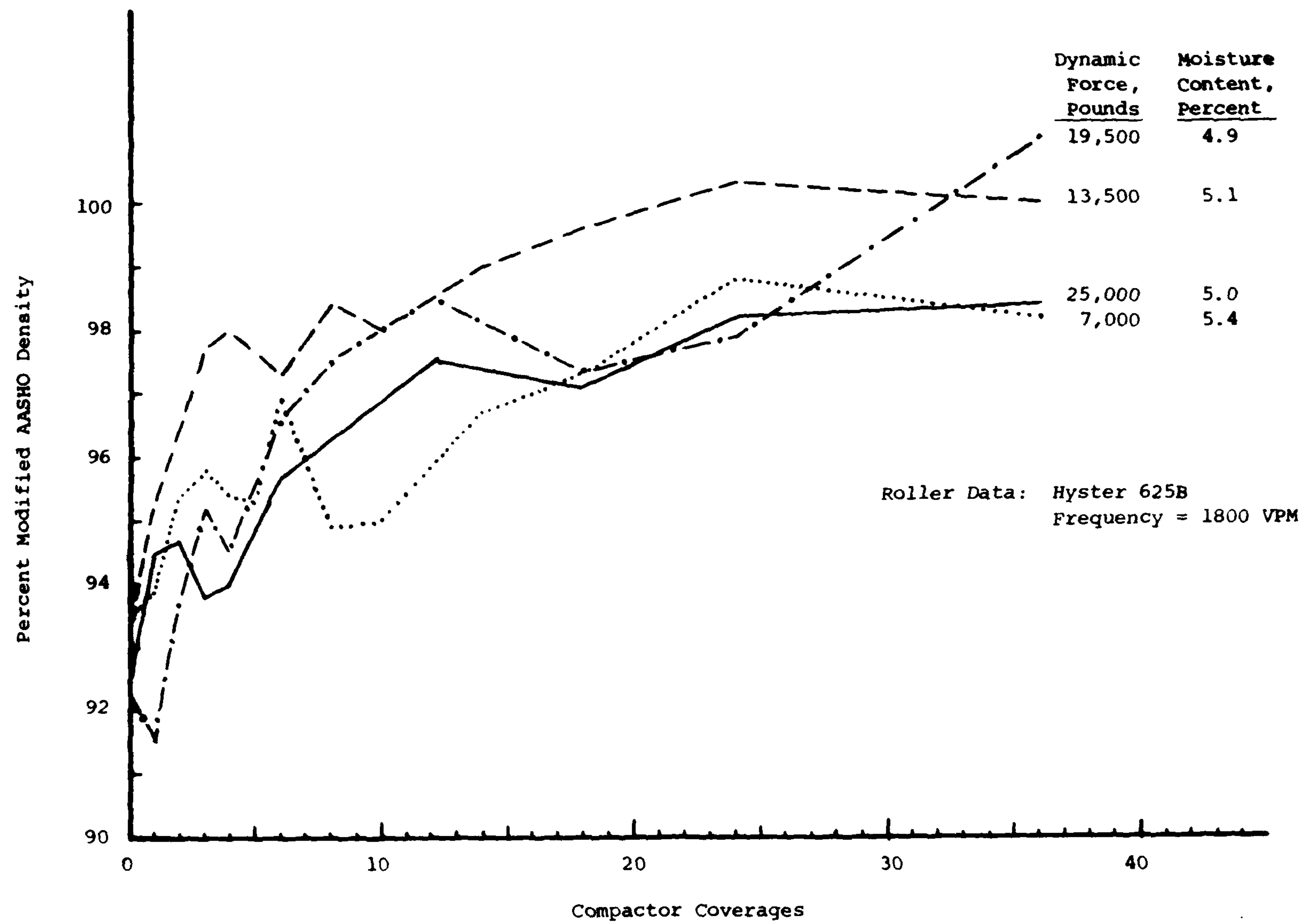

Figure 19. Effect of Dynamic Force at High Moisture Contents

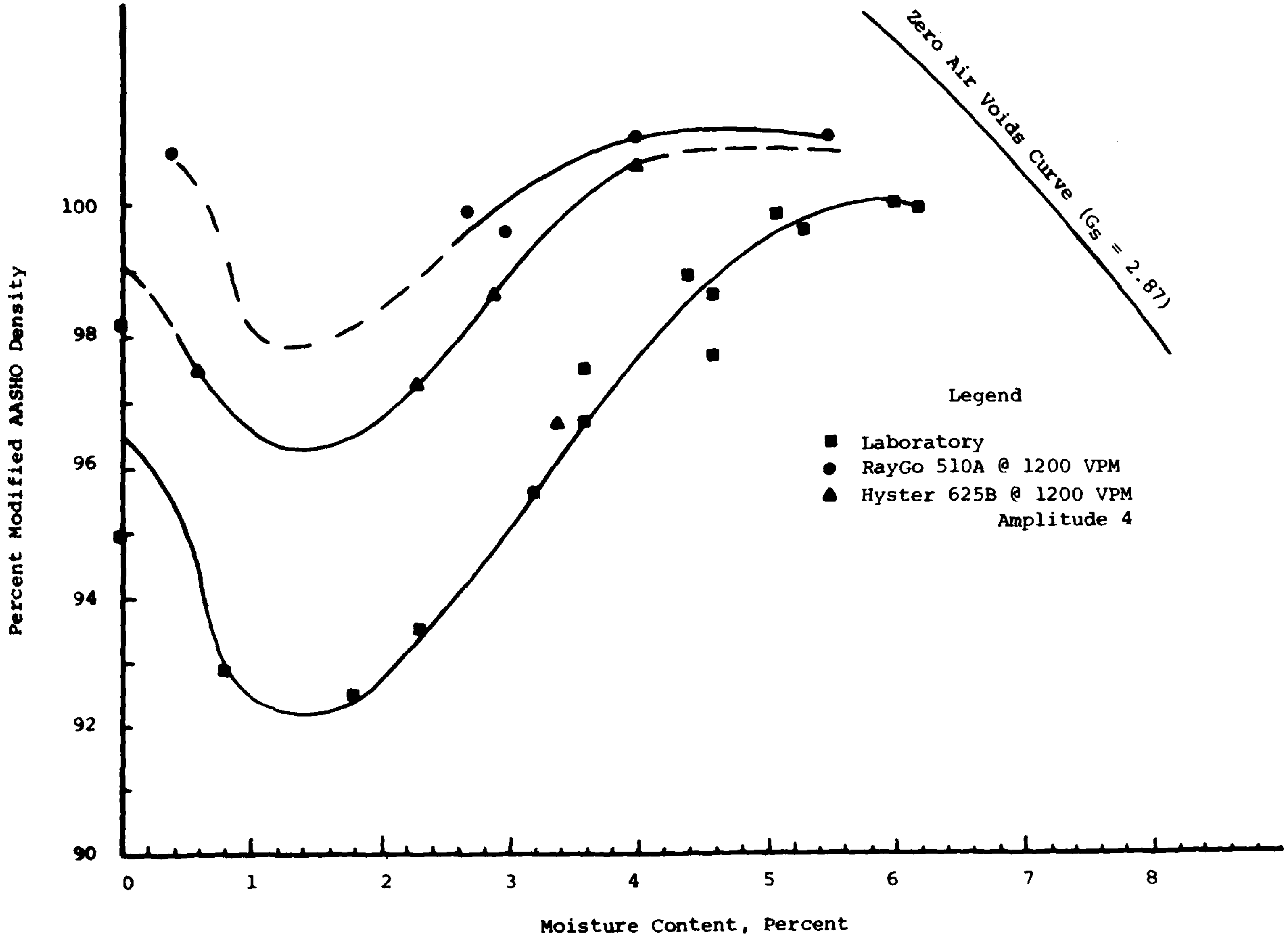

Figure 20. Effect of Moisture Content on Vibratory Compaction

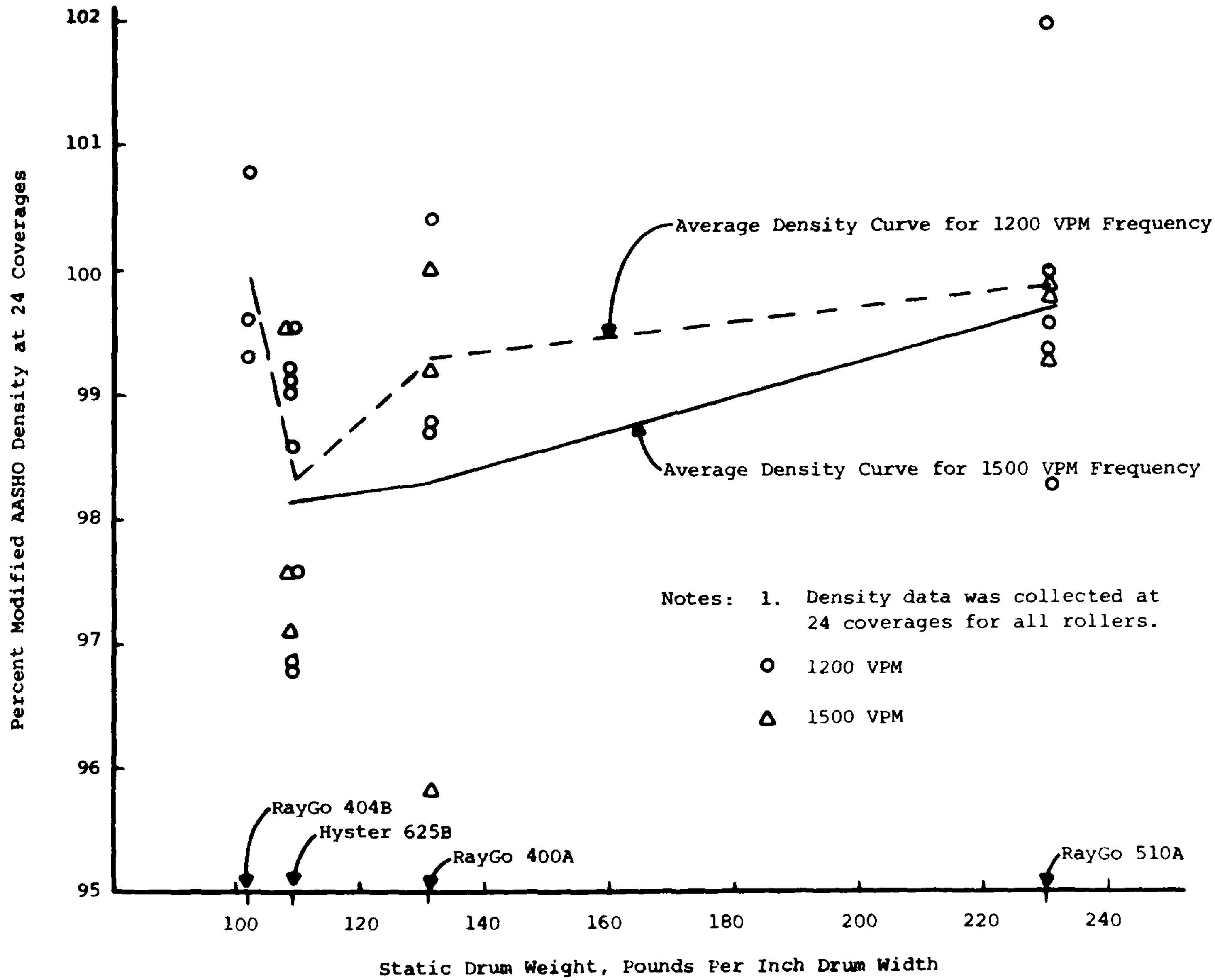

Figure 21. Effect of Static Weight on Vibratory Compaction

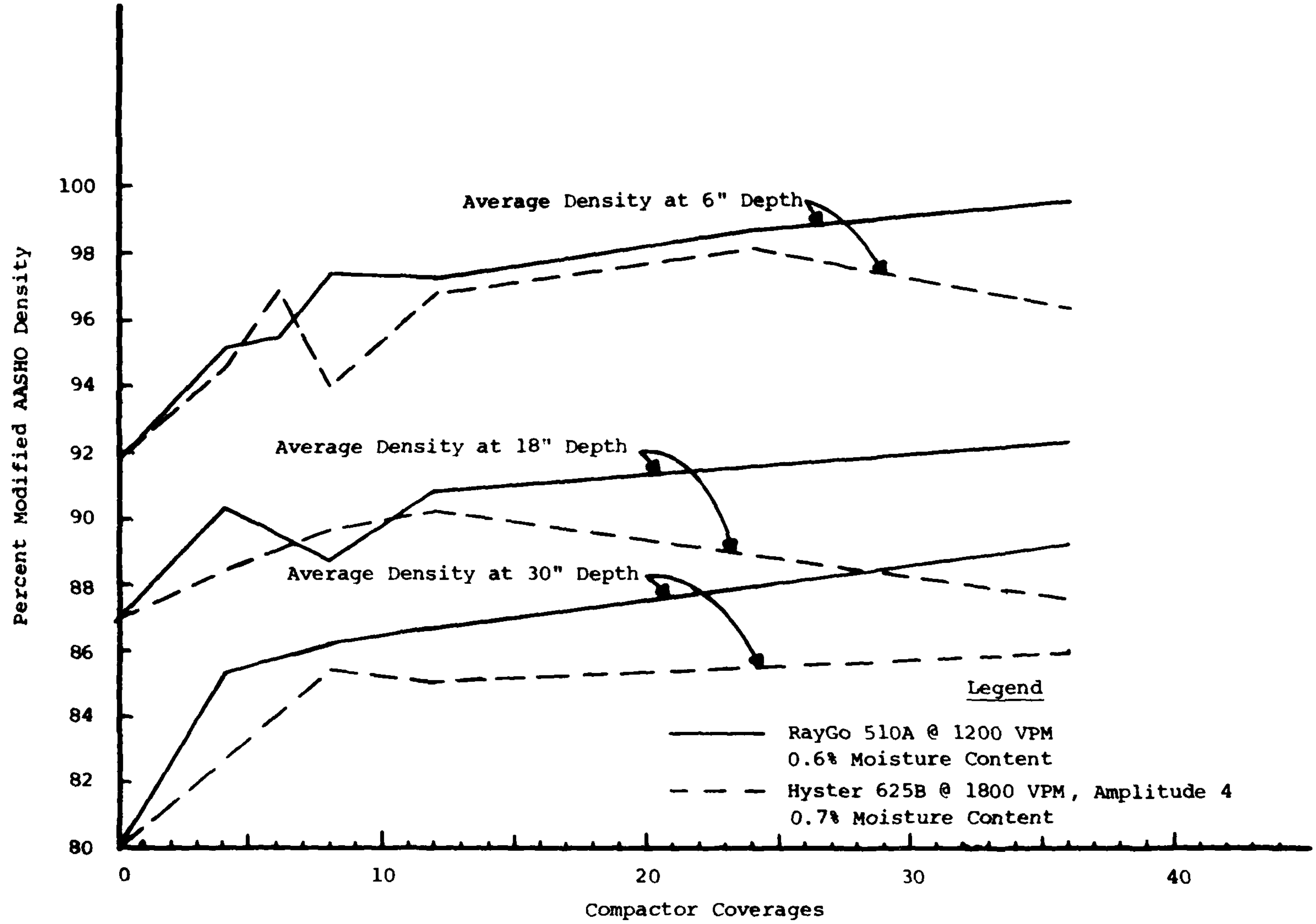

Figure 22. Deep Lift Test Results at Dry Moisture Contents

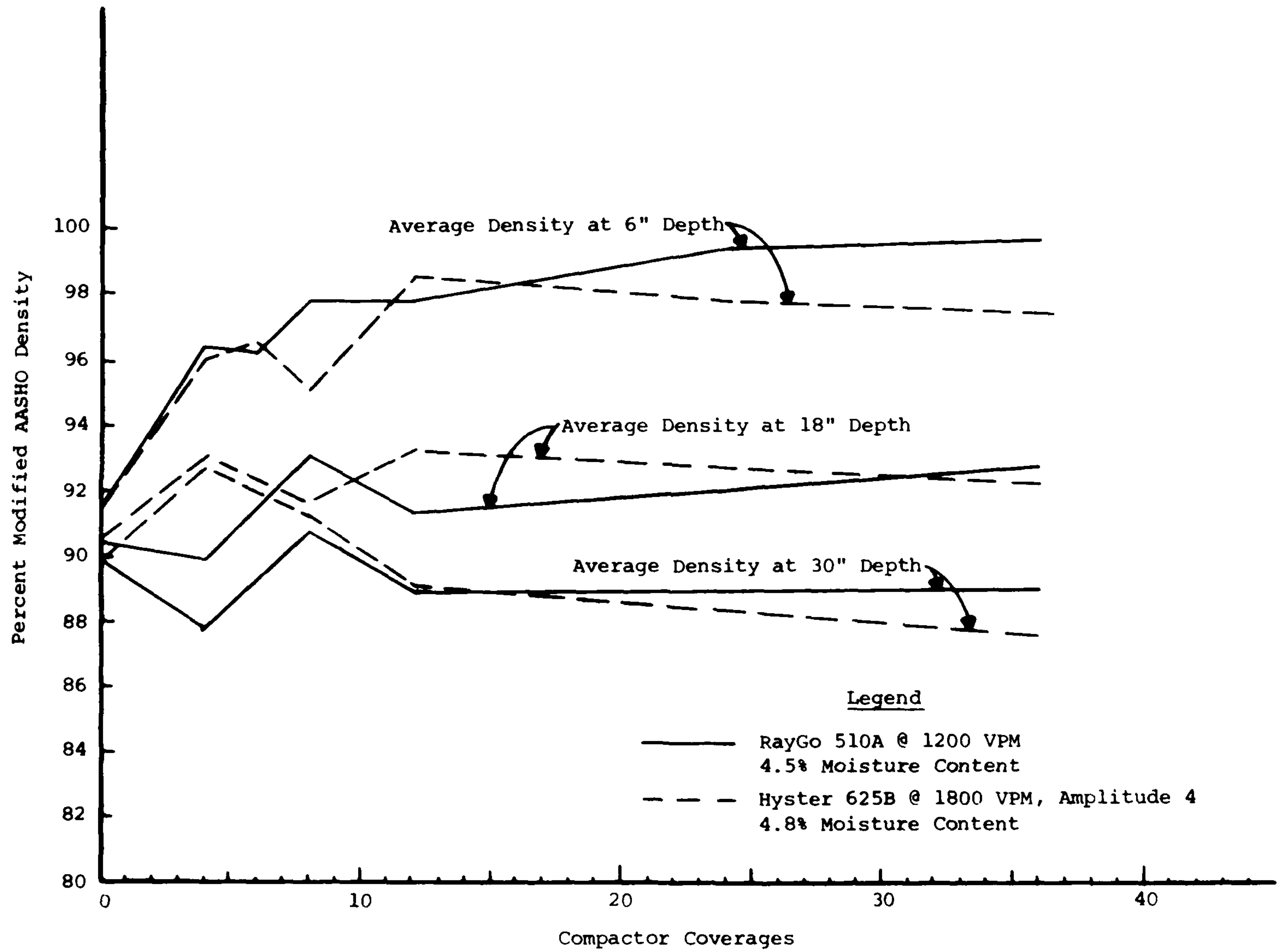

Figure 23. Deep Lift Test Results at Medium Moisture Contents

state-of-the-art, selection of the optimum frequency for a vibratory roller on a given soil with a given moisture content is a trial-and-error procedure. The optimum frequency for compaction will vary with the characteristics of the roller, the properties of the soil, and the moisture content.

Dynamic Force - Most manufacturers provide a dynamic force rating for vibratory rollers. This dynamic force is calculated from the following equation:

$$F = Me^{2}$$

where

F = force

M = mass

e = distance from center of gravity of eccentric mass to center of rotation

= angular velocity of the rotating mass

Dynamic stress measured in the soil has been found to be a major factor in densification using vibratory rollers (References 10 and 11). However, the nominal dynamic force calculated for vibratory rollers by the previous equation is unrelated to the actual forces acting on the soil. This is due to damping in the roller and the soil and to the effects of inertial forces and phase lag which will all vary depending on specific roller and soil conditions. Attempts to rate the effectiveness of vibratory rollers on the basis of this dynamic force alone have not been successful (References 12 and 13).

These problems may be at least partially explained by Yoo and Selig's compaction model, which predicts the force actually transmitted to the soil will tend to level off to a constant value at higher generated dynamic force values, as illustrated in Figure 16 (Reference 7).

The Hyster 625B vibratory roller offered four amplitude settings which provided a range of nominal dynamic forces from 7,000 to 25,000 pounds, at a constant frequency of 1,800 vpm. Figures 17 through 19 show the change in density with increasing dynamic force settings and at varying moisture contents. With the exception of a dynamic force setting of 13,500 pounds, the remaining three dynamic force settings tend to result in very similar compaction curves. This observation would support Yoo and Selig's prediction that dynamic forces tend to level off to a constant value. However, the variation of the 13,500-pound dynamic force setting (ranging from low to high curves) seems to defy explanation.

In any case, the use of dynamic force as a means of evaluating a vibratory roller's effectiveness can be very misleading and should be avoided.

Moisture Content - The importance of moisture content in soil compaction has been known, if not heeded, since the studies by Procter in the 1930's. The results of this study once again underline the importance of moisture content in soil compaction.

Figure 20 shows the densities obtained by two of the rollers after 36 coverages as a function of moisture content. The density data are plotted at the moisture content just prior to the start of compaction. Consequently, some of the wetter test sections drained during compaction, and the final moisture contents are less than those shown in Figure 20. Also plotted on Figure 20 are the densities obtained in the laboratory using the modified AASHO method. The laboratory curve and the plot of field data support previous conclusions by Fry and Burns (Reference 4) that cohesionless aggregate with less than 10 percent fines is best compacted at the maximum moisture content possible, or as dry as possible. Compaction in the 1.0 to 2.5 percent moisture content range should be avoided if possible.

Static Weight - Previous investigators of vibratory rollers have found that the static weight of the roller is the best available indicator of performance for vibratory compaction of base course materials (References 12, 13, 14, and 15). Such a conclusion is not so easily reached based on the data collected in this study.

Figure 21 shows the density achieved after 24 coverages of the vibratory roller as a function of the roller's static drum weight. The curves connect the average density for each roller. For rollers operating at a frequency of 1500 vpm, there is a small increase in density with increasing roller weight. For a 1200 vpm frequency no trend is readily evident. The two smaller rollers with nearly identical static weights had average densities that were 1.6 percent apart. This difference is probably due to either scatter in the data or differences in the stiffness and damping characteristics of the two rollers. (For these same reasons, caution should be used in drawing any conclusions regarding static weight from Figure 20, which shows the moisture-density relationships for the RayGo 510A and the Hyster 625B.) Looking strictly at the densities for the RayGo rollers shown in Figure 21, and assuming that the stiffness and damping characteristics of these three rollers are comparable, there is apparently no significant effect due to static roller weight at 1200 vpm frequency. These observations apply only to the 15-inch lifts of crushed limestone tested during the initial roller evaluation tests.

Deep Lift Tests - Previous investigators have often found that vibratory rollers are capable of deeper compaction than conventional equipment (References 12, 14, and 16), but all tests have not unanimously supported this contention (Reference 13). The ability to obtain density at depth is critically important in the RRR mission and is a major question to be resolved in these tests.

To evaluate the effectiveness of vibratory rollers in compacting thick crushed limestone lifts, the lightest and heaviest rollers were selected and operated at one of their best machine settings (Hyster 625B: 1800 vpm frequency and amplitude setting 4; RayGo 510A: 1200 vpm frequency). These rollers were used to compact 40-inch lifts of crushed limestone. The average density from 0 to 12 inches, 12 to 24 inches, and 24 to 36 inches in depth were determined with the nuclear density guage. These average densities were applied at the 6-inch, 18-inch and 30-inch depths, respectively, for analytical purposes.

Figures 22 and 23 show the increase in density with increasing coverages of the roller at dry and medium moisture contents, respectively. For the dry crushed limestone the heavier roller did a superior job of compaction at all depths, but this edge over the lighter roller was insignificant for the crushed limestone at a medium moisture content. Perhaps more important in comparing the two rollers was the consistency of density achieved by the heavier roller. The density at all depths was virtually identical for the heavier roller at either moisture content; the lighter roller varied up to 1.3 percent maximum density in compacting the dry and the damp limestone.

In general, the dry limestone seemed to be more affected by vibratory compaction than was the medium moisture content limestone. Also, while the heavier vibratory roller did a more consistently superior job of compaction than did the lighter roller, its ability to compact thick lifts of crushed stone seems clearly limited. Average density in the 24- to 36-inch depth did not exceed 88.6 percent maximum density; density in the 12- to 24-inch depth averaged no more than 92.4 percent maximum density.

F-4 LOADCART TESTS

Description

Based primarily on the results of the deep lift tests with the RayGo 510A and the Hyster 625B (the largest and the smallest rollers, respectively), the two largest rollers (the RayGo 510A and 400A) were selected for the F-4 loadcart tests. For these tests 1 1/2-inch graded crushed limestone was placed in test pits at the Small Crater Test Facility at various moisture contents. The limestone was then compacted with 32 coverages of the roller being tested. Note that the Troxler nuclear density gauge was not operating properly during this phase of the testing, so only sporadic data on density during compaction and trafficking is available.

After compaction, simulated F-4 aircraft traffic was applied using the loadcart shown in Figure 24, which applied a 27,000 pound main gear load at a tire pressure of 265 psi. Traffic was applied in an approximated normal traffic distribution over a 10 foot width, as shown in Figure 25. The loadcart was driven forward and back in the same wheel path prior to moving to the next lane. A total of 96 pases of the gear load were placed on the test item to obtain 10 coverages of the loadcart in the center six lanes, eight coverages in the four lanes adjacent to the center, and two coverages in the two outside lanes. This traffic distribution is representative of actual aircraft traffic distribution on a runway and avoids introducing a sharp discontinuity between trafficked and untrafficked areas (Reference 17).

Table 3 summarizes each loadcart test. F-4 loadcart traffic was applied until a three-inch rut developed, or until 150 coverages (1440 passes) were achieved. Repairs to the test items were permitted if needed after 10 coverages (96 passes) had been applied.

Data Analysis

Seven tests were conducted which compacted a 24-inch lift of graded crushed limestone over a soft clay subgrade and then trafficked the crushed stone with an F-4 loadcart. The lighter of the two rollers tested, the RayGo 400A, was used in four tests with crushed stone at moisture contents ranging from 2.2 to 5.5 percent. The heavier roller, the RayGo 510A, was used to compact crushed limestone at three moisture contents in the 4.9 to 5.7 percent range. Of the seven tests, four were termed either failures or marginal; three were termed successful, having achieved 150 coverages (1440 passes) of the F-4 loadcart.

Figure 26 shows the density of the crushed limestone as a function of coverages of the roller and the F-4 loadcart. The data is somewhat sporadic due to problems with the nuclear density gauge. Nevertheless, this graph shows that low density did not cause the failures in the traffic tests. The highest density achieved after compaction was a failure (the RayGo 400A at 5.5 percent moisture content), and one of the lowest densities after compaction was successful (the RayGo 400A at 2.2 percent moisture content).

High moisture content seemed to be the common factor among the failures and marginal successes, all of which occurred at moisture contents in excess of 5 percent. Looking at Table 3, the RayGo 400A sufficiently compacted the crushed limestone at moisture contents of 2.2 and 4.0 percent to carry F-4 loadcart traffic. Each test item required only one repair to add more material due to consolidation of the crushed limestone. However, at moisture contents of 5.4 and 5.5 percent, the crushed limestone failed almost immediately due to rutting. The compacted limestone was very spongy under the weight of a person's

TABLE 3
F-4 LOADCART TESTS

ROLLER	FREQUENCY	MOISTURE CONTENT	COVERAGES F-4 LOADCART	COMMENTS
RAYGO 400A	1500 VPM	2.2%	150	One repair
		4.0%	150	One repair
		5.4%	2	Failure
		5.5%	6	Failure
RAYGO 510A	1500 VPM	4.9%	150	One repair
		5.4%	54	Marginal, one repair
		5.7%	26	Marginal, repair failed

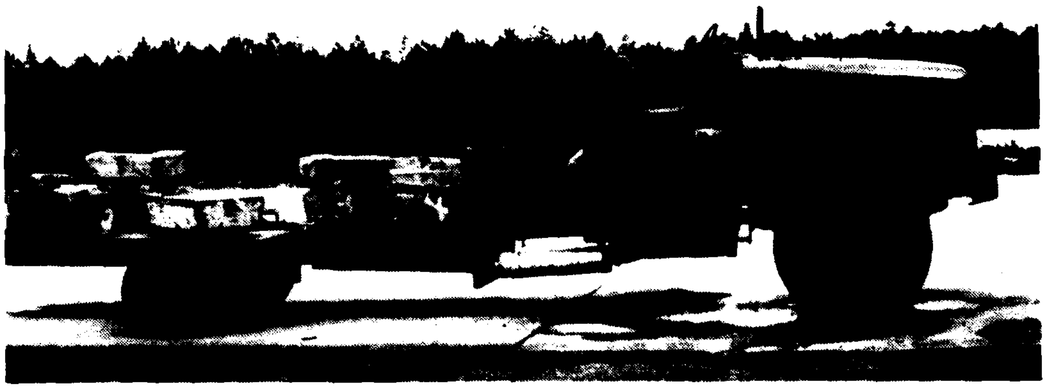

Figure 24. F-4 Loadcart

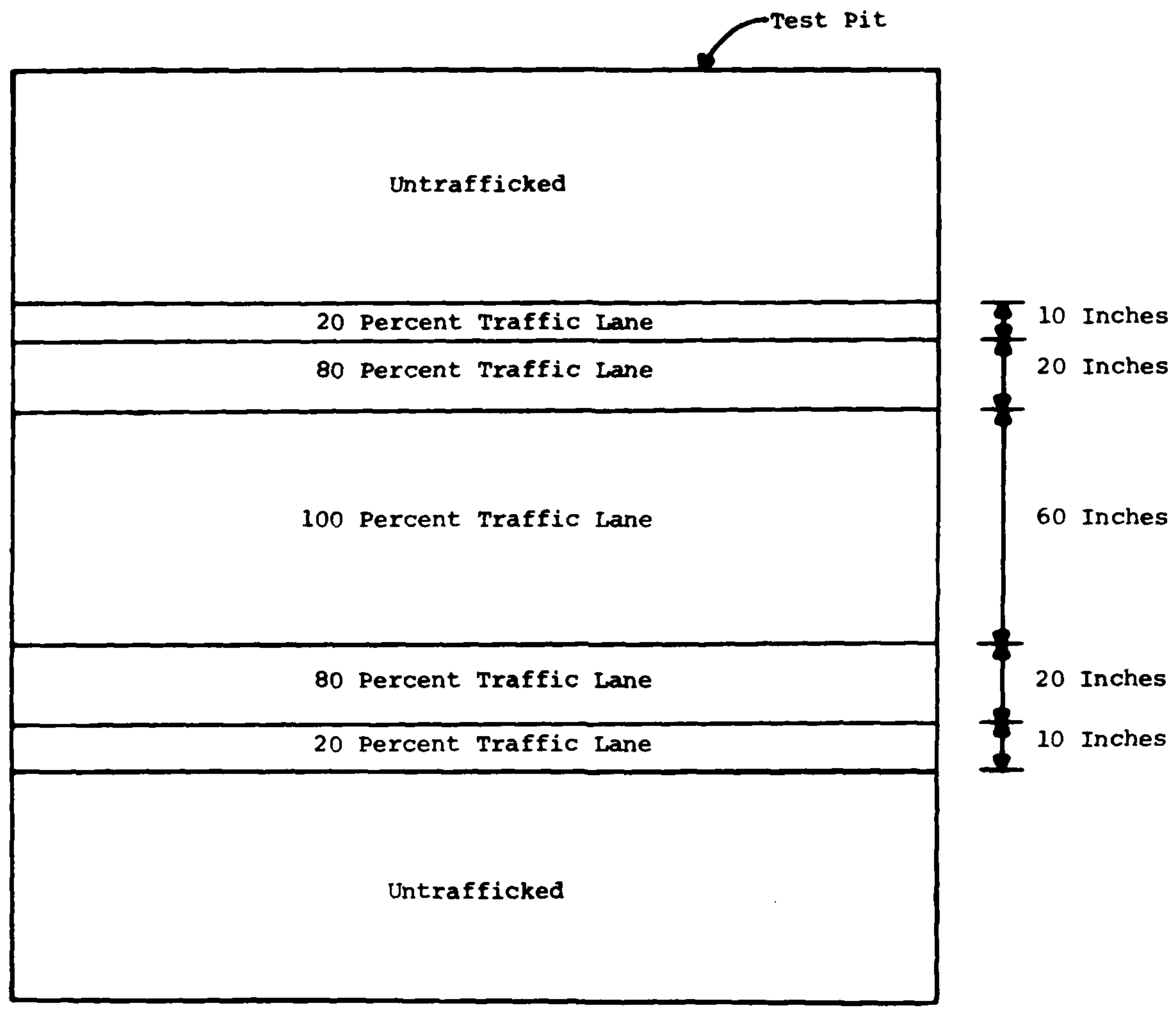

Figure 25. Traffic Pattern for F-4 Loadcart

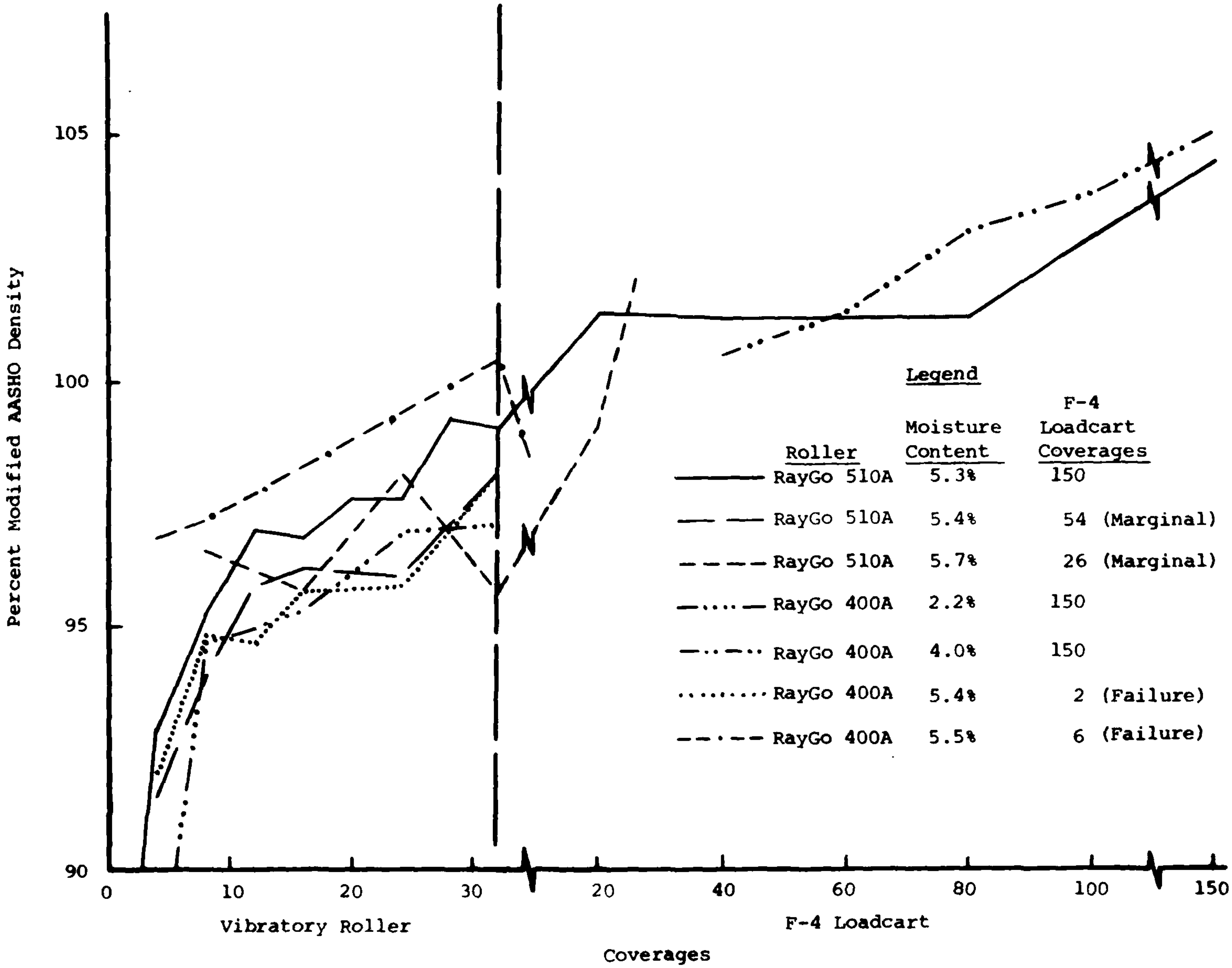

Figure 26. F-4 Loadcart Test Results

foot, and water was observed running out of the pit. Similar observations were made of the tests run with the heavier RayGo 510A. At a moisture content of 4.9 percent, the RayGo 510A was able to compact the crushed limestone enough to support F-4 loadcart traffic. One repair was required to the test item to add more material due to consolidation of the crushed limestone. However, when the moisture content was at 5.4 and 5.7 percent, the performance of the test item degraded to marginal. At a moisture content of 5.4 percent, only 54 coverages (with an early repair to correct shoving problems) were applied before the test item failed. This failure was characterized by excessive shoving and movement of the crushed limestone, which eventually led to bogging down the F-4 loadcart and rutting the surface. At 5.7 percent moisture content, the repair failed at 26 coverages in a manner similar to the previous item. Based on these results, it would seem that the heavier roller would be preferred due to its lesser sensitivity to moisture, which is clearly seen in Table 3. At comparable moisture contents, the limestone compacted with the RayGo 510A was capable of supporting significantly more traffic than was limestone compacted with the lighter RayGo 400A.

The causes of the traffic test failures and near-failures are debatable. Tests by Nettles and Calhoun (Reference 18) have shown that the base course material such as used in these tests has very low permeability when compacted to high densities. The low permeability of the tested aggregate when compacted to high density may have resulted in pore pressures developing under traffic, which, in turn, led to reduced soil strength and eventual failure. Other possible explanations for the spongy surface include over-lubrication of the aggregate particles by water, or the dilation of the aggregate when sheared, which would permit water to infiltrate the crushed limestone.

Figures 27 through 31 are surface profiles of the test items taken along the center of the crater perpendicular to traffic (the two failures were not profiled). These profiles show the settlement of the crushed limestone during F-4 loadcart trafficking. Of particular interest is Figure 29, which shows that insignificant settlement occurs after 40 coverages (384 passes) of the loadcart. Based on this test (which was the first traffic test run), repairs to the test items were generally made after 40 coverages unless required sooner.

These tests demonstrated that a vibratory roller can compact a 24-inch layer of crushed limestone to sufficient density to support minimal F-4 traffic (20 to 40 coverages). In addition, the effectiveness of surface repair and maintenance in extending the life of the repairs to 150 coverages or more has been demonstrated. However, moisture content appears to be the critical factor determining success or failure of a crushed limestone repair. This sensitivity to moisture can apparently be lessened by going to heavier vibratory rollers.

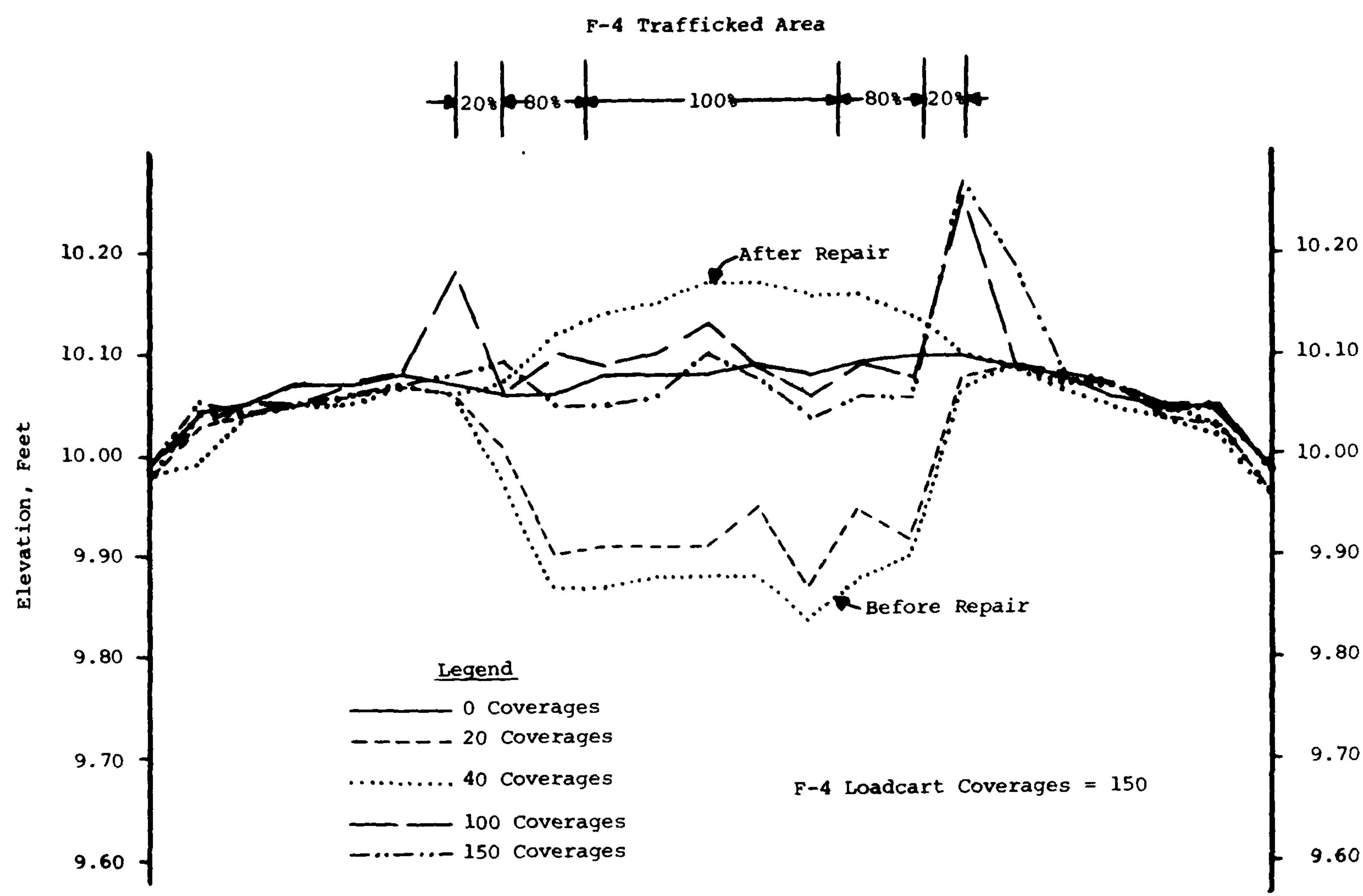

Figure 27. Surface Profiles: RayGo 400A, 2.2% Moisture Content

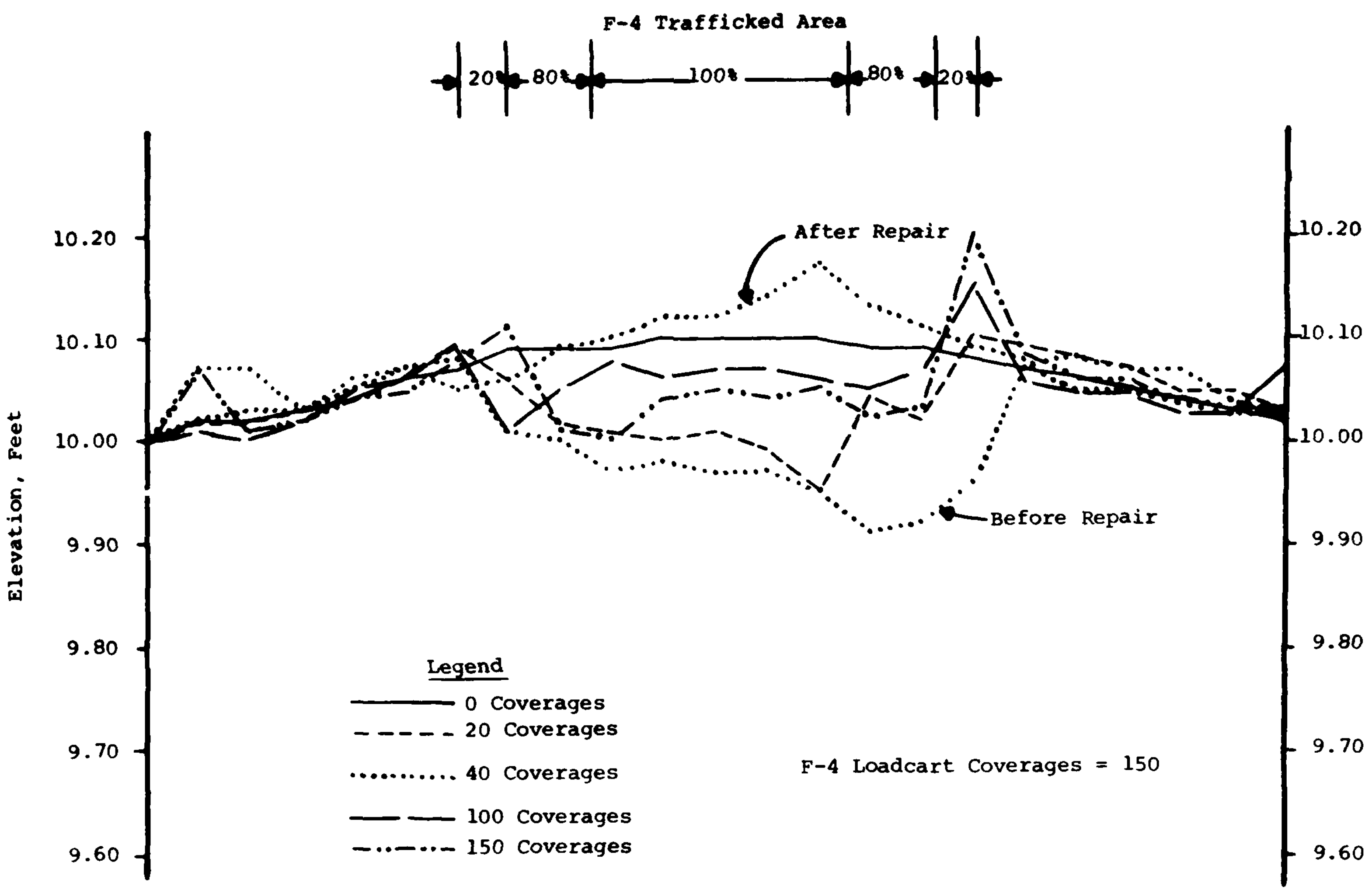

Figure 28. Surface Profiles: RayGo 400A, 4.0% Moisture Content

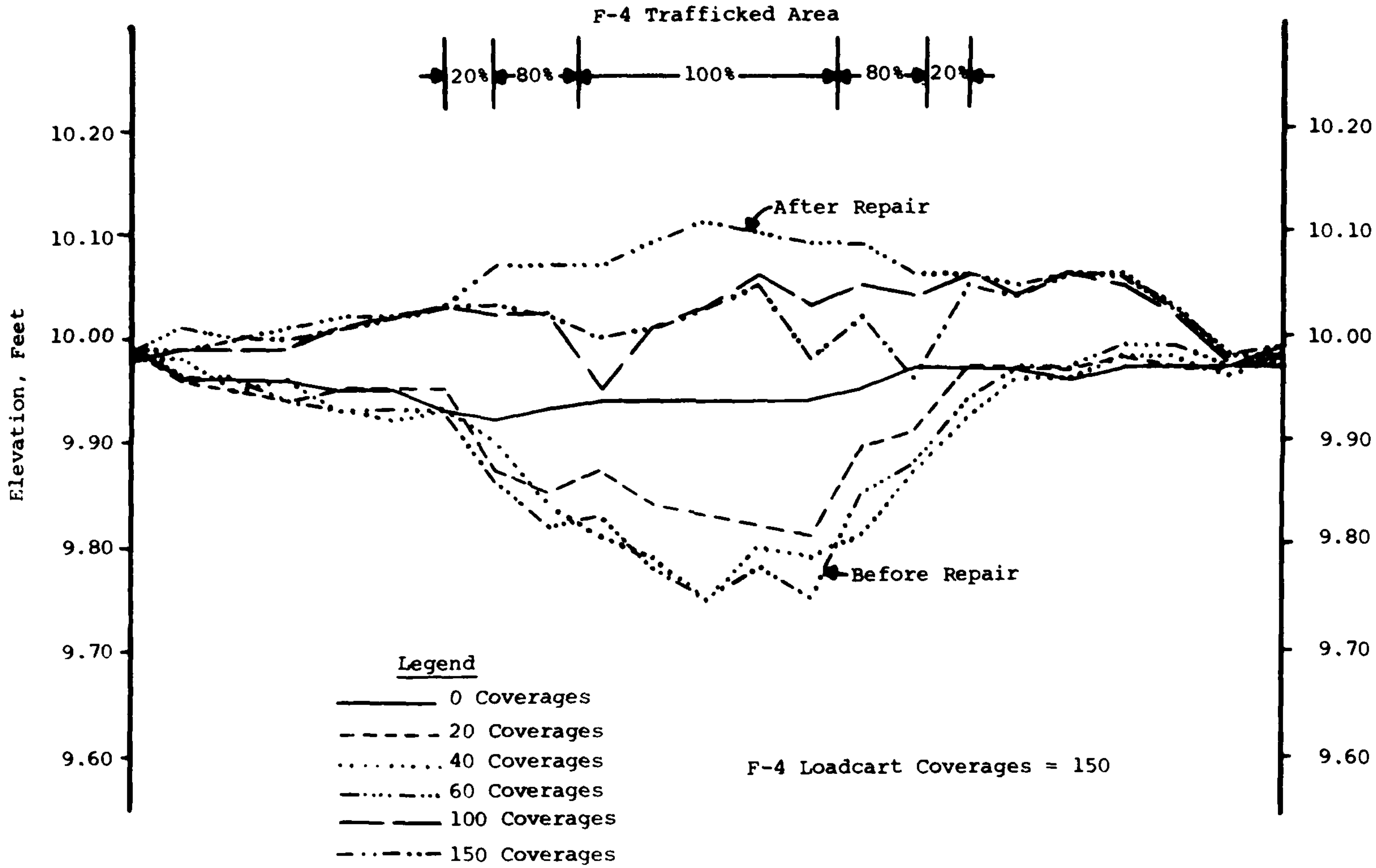

Figure 29. Surface Profiles: RayGo 510A, 4.9% Moisture Content

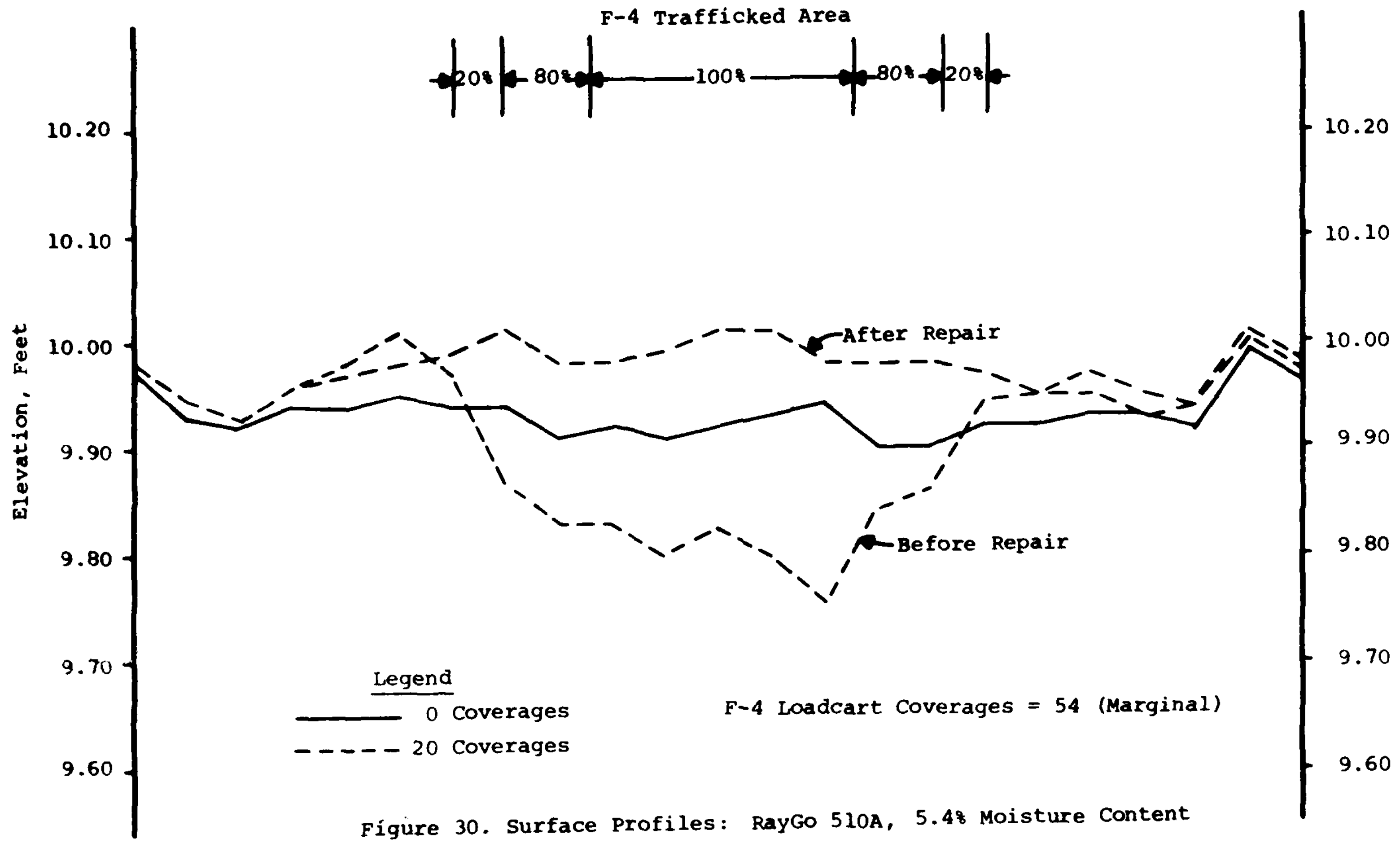

Figure 30. Surface Profiles: RayGo 510A, 5.4% Moisture Content

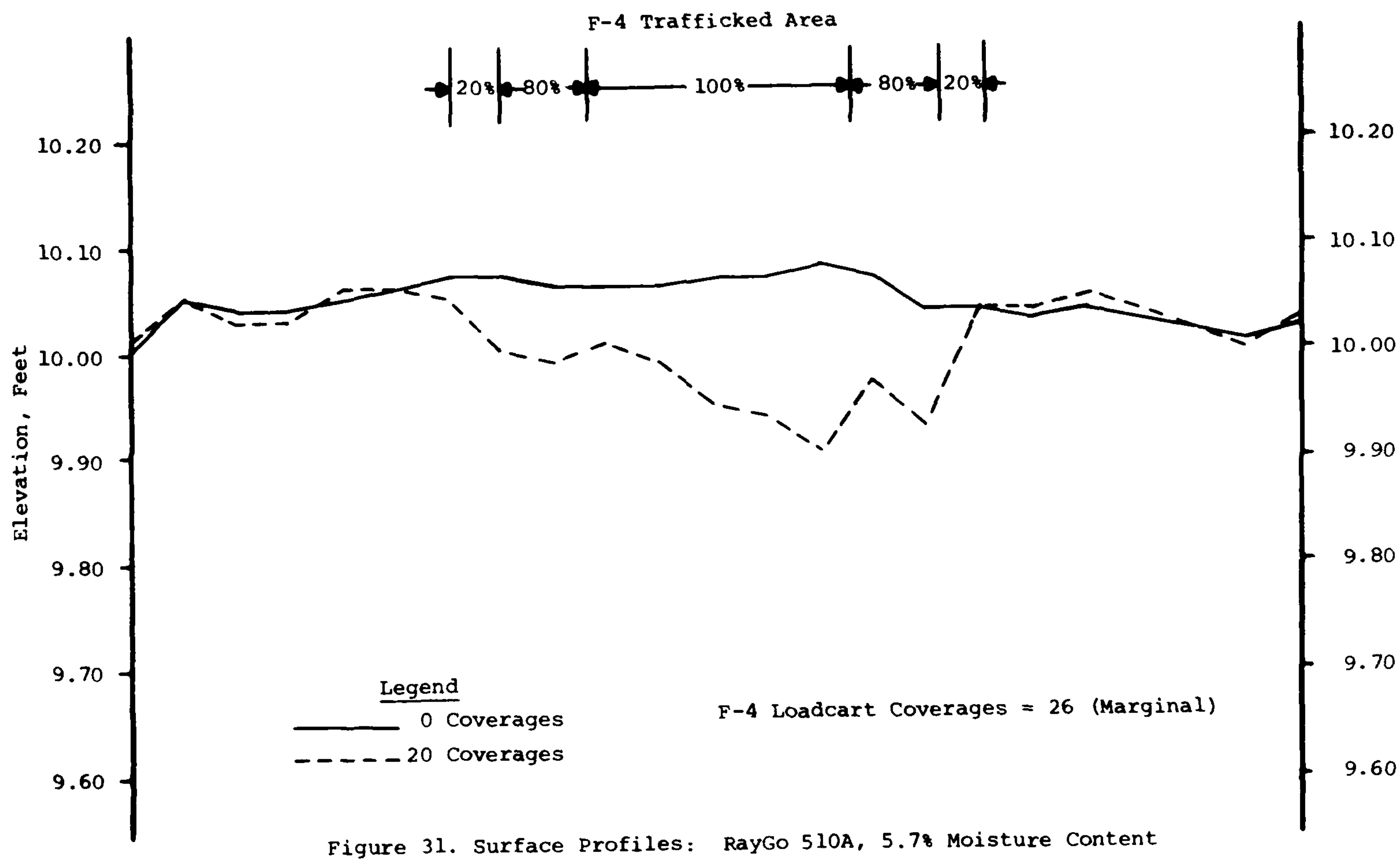

Figure 31. Surface Profiles: RayGo 510A, 5.7% Moisture Content

SUMMARY

The desired compactor for Rapid Runway Repair (RRR) must be capable of compacting a single loose lift of quality base course aggregate to support emergency operation of aircraft. The trafficking tests indicate that it is feasible to accomplish this with vibratory rollers.

The initial roller evaluation tests showed that it is possible to take lighter rollers such as the Hyster 625B or the RayGo 404B and, by adjustments in the frequency, equal or exceed the performance of the heavier rollers in 15-inch-thick lifts (Figure 21). However, the current lack of understanding of vibratory compaction prevents any predictions on performance at different frequency settings. Each roller-soil system would have to be evaluated separately. This would require careful quality control testing, which is out of the question for the emergency environment of a Rapid Runway Repair scenario.

Looking at Figure 26, if the test with the RayGo 510A at 5.7 percent moisture content is considered unacceptable, then 97 percent modified AASHO density in the upper 12 inches would seem to be an acceptable required density for expedient repairs using base course materials. This is a considerable reduction from previous recommendations of 100 percent in the upper 12 inches (Reference 1). All of the rollers tested were capable of achieving this level of compaction; however, there is no data to evaluate the density requirements below the upper 12 inches of the repair. Based on the results of the deep lift test during the initial roller evaluation tests, the heavier rollers seem better able to achieve significant density improvements at depth under a wider range of moisture conditions. Additionally, the F-4 loadcart tests showed that the heavier roller was less sensitive to moisture content in the crushed limestone. With all of the rollers tested, however, moisture control remains a critical parameter in vibratory compaction. This poses a major problem in RRR since repairs may have to be made under wet conditions.

As expected, none of the vibratory rollers tested was a panacea for RRR. However, the heavier rollers (RayGo 400A and RayGo 510A) seemed best able to compact crushed limestone under a broader range of conditions than did the lighter rollers.

SECTION IV

CONCLUSIONS

1. It is feasible to construct rapid runway repairs for limited F-4 tire loads by compacting 24-inch-thick lifts of crushed limestone base course aggregate with heavy vibratory rollers (over 10 tons machine weight).

2. At least for rollers up to 17-ton machine weight, the heavier the roller, the better its performance for RRR.

3. Moisture control is critical for vibratory compaction of crushed limestone for RRR. Excessive moisture will reduce the number of aircraft passes the repair can support.

4. The interaction of a number of parameters makes it currently impossible to predict performance of different vibratory rollers on different soils, or to even allow dependable recommendations on frequency and amplitude (dynamic force) settings for the rollers. The state-of-the-art remains trial-and-error tests of a specific roller on a specific soil to develop optimum moisture, frequency, and amplitude selections.

SECTION V

RECOMMENDATIONS

1. Tests should be conducted to determine:

a. Effect of low and intermediate moisture contents (0 and 3 percent) on the acceptability of crushed stone repairs.

b. Minimum number of coverages of the vibratory roller required to compact crushed stone repairs for RRR.

2. The requirement for Foreign Object Damage (FOD) covers over the crushed stone repair should be investigated.

3. Other base course materials besides limestone should be tested for use in RRR repairs. Special attention should be given to materials available locally to the eventual users (USAFE, PACAF, etc.).

4. Testing should be conducted to identify an improved gradation range of base course materials which will avoid or minimize problems associated with high moisture contents while retaining adequate strength characteristics to be used in RRR repairs.

5. Alternate means of compaction should be investigated. This may include concepts such as:

a. Dynamic compaction (Reference 19).

b. Large vibratory plate compactors mounted on cranes, backhoes, etc.

c. Use of a subbase such as sand which is more easily compacted by vibratory equipment, or subbases/bases which can be rapidly stabilized to reduce compaction requirements.

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APPENDIX A

DENSITY DATA

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 2
DYNAMIC FORCE: 5000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.5	138.9	138.7	139.9
1	.3	140.4	140.7	140.2
2	.3	142.9	141.9	142.1
3	.4	142.1	142.0	139.8
4	.4	142.3	142.0	140.2
5	.2	142.3	142.9	141.0
6	.4	141.6	142.9	141.4
8	.5	141.9	140.6	144.5
10	.6	143.5	141.7	141.2
14	.5	145.8	145.1	143.1
18	.4	143.6	144.4	143.0
24	.4	145.7	144.4	144.8
36	.3	145.9	145.3	146.3

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 2
DYNAMIC FORCE: 5000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	3.8	132.3	135.4	134.4
1	3.7	134.1	135.7	136.3
2	3.8	139.7	137.8	136.7
3	3.7	138.3	137.9	137.8
4	3.8	138.8	138.9	137.7
5	3.6	139.7	139.2	139.4
6	3.4	138.9	139.4	139.2
8	3.8	139.9	138.9	139.1
10	3.7	140.5	141.4	139.9
14	3.7	139.8	139.8	141.1
18	3.6	143.5	141.8	141.3
24	3.6	144.5	143.1	141.3
36	3.7	145.7	144.8	143.7

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 2
DYNAMIC FORCE: 5000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	6.4	137.6	138.0	138.4
1	6.1	138.7	139.2	137.8
2	6.6	139.5	139.0	139.6
3	5.9	141.8	140.2	141.0
4	5.4	141.2	141.2	139.9
5	5.2	142.4	141.0	139.2
6	5.3	140.2	138.3	138.7
8	5.1	140.9	140.5	138.8
10	5.5	141.7	140.8	141.9
14	5.1	143.6	142.9	142.9
18	5.4	144.5	143.7	144.6
24	5.2	146.7	144.0	143.9
36	5.2	147.4	146.2	145.0

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 4
DYNAMIC FORCE: 9500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.6	128.2	133.0	134.8
1	.6	135.5	137.0	133.3
2	.6	136.4	138.3	139.7
3	.6	134.2	136.8	138.7
4	.5	136.7	137.6	138.6
5	.6	139.7	140.3	141.5
6	.7	138.9	140.2	140.8
8	.5	140.6	141.3	143.4
10	.5	141.0	141.6	140.9
14	.5	141.2	141.1	142.5
18	.5	140.2	142.9	143.3
24	.5	144.6	144.1	144.7
36	.6	144.0	143.0	142.3

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 4
DYNAMIC FORCE: 9500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.7	125.7	129.9	130.1
1	4.5	130.7	133.1	132.8
2	4.4	133.0	135.3	135.4
3	4.3	134.9	136.6	137.9
4	3.8	137.6	139.4	139.4
5	3.9	138.1	139.2	138.6
6	3.8	137.6	139.1	140.3
8	3.9	140.3	139.7	137.5
10	3.8	140.3	139.4	141.8
14	3.8	141.2	142.3	142.3
18	3.6	143.8	142.2	142.6
24	3.6	145.3	143.7	141.5
36	3.4	144.1	142.5	141.2

ROLLER: HYSTER 625H FREQUENCY: 1200
AMPLITUDE: 4
DYNAMIC FORCE: 9500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.7	134.2	136.8	134.0
1	4.9	136.0	135.3	137.8
2	4.7	138.6	139.7	139.8
3	4.8	138.6	141.1	141.6
4	4.8	141.9	142.0	142.8
5	4.9	141.6	142.4	143.6
6	4.5	143.0	143.3	143.7
8	4.6	139.9	141.2	142.2
10	4.2	140.3	141.1	141.5
14	4.3	142.6	141.5	142.8
18	4.2	142.9	144.6	144.4
24	4.0	145.9	145.1	145.3
36	4.0	144.9	145.1	146.0

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H   FREQUENCY: 1200
AMPLITUDE: 4
DYNAMIC FORCE: 9500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	2.6	130.6	132.7	132.5
1	2.3	135.6	135.3	134.8
2	2.4	136.4	136.3	132.6
3	2.4	137.8	135.6	133.4
4	2.4	136.6	136.0	134.5
5	2.5	139.1	137.7	138.6
6	2.4	138.3	138.4	138.2
8	2.3	139.6	139.2	138.4
10	2.4	138.6	138.6	139.1
14	2.4	138.0	140.2	139.7
18	2.3	142.3	142.0	141.4
24	2.4	143.8	143.4	142.5
36	2.3	144.1	143.4	142.0

ROLLER: HYSTER 625H   FREQUENCY: 1200
AMPLITUDE: 4
DYNAMIC FORCE: 9500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	3.1	129.7	128.9	129.1
1	2.8	129.8	131.5	131.7
2	2.8	133.2	132.6	132.5
3	2.9	134.8	134.8	134.1
4	2.8	135.0	135.3	133.1
5	3.2	132.2	135.5	134.4
6	2.8	137.2	137.1	136.6
8	2.8	136.7	137.5	138.5
10	2.9	138.5	139.8	140.5
14	3.1	139.7	141.1	141.7
18	2.8	141.8	142.3	142.2
24	2.8	140.7	145.0	144.6
36	2.9	144.1	144.5	143.9

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H   FREQUENCY: 1500
AMPLITUDE: 2
DYNAMIC FORCE: 9000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.3	136.0	136.4	134.5
1	.4	137.7	137.8	138.9
2	.4	140.4	139.8	137.9
3	.5	140.4	140.3	137.6
4	.5	141.1	140.2	138.0
5	.3	142.6	141.4	141.0
6	.5	142.2	141.0	139.3
8	.5	139.2	139.6	141.8
10	.4	140.6	141.7	142.7
14	.3	143.5	142.8	141.9
18	.6	143.1	141.3	141.8
24	.4	143.9	143.3	142.5
36	.4	146.2	144.5	144.2

ROLLER: HYSTER 625H   FREQUENCY: 1500
AMPLITUDE: 2
DYNAMIC FORCE: 9000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.0	128.8	131.9	133.2
1	4.3	133.0	134.1	132.6
2	4.3	136.0	135.2	134.9
3	4.5	136.2	135.9	134.5
4	4.4	137.6	138.1	136.6
5	3.9	140.1	140.2	138.7
6	4.1	139.5	139.7	138.1
8	4.1	141.9	138.9	139.9
10	4.1	139.5	138.4	137.2
14	3.9	141.4	140.5	141.2
18	4.0	141.2	141.1	138.4
24	3.9	143.2	142.4	141.7
36	3.8	144.0	144.4	143.3

ROLLER: HYSTER 625H   FREQUENCY: 1500
AMPLITUDE: 2
DYNAMIC FORCE: 9000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	6.1	136.7	136.0	136.9
1	6.4	137.0	137.0	137.4
2	6.9	137.7	137.5	137.8
3	6.2	140.8	139.3	136.1
4	6.0	140.6	142.0	141.9
5	5.7	143.0	142.0	142.0
6	5.5	143.4	143.1	143.9
8	5.5	143.8	143.1	144.8
10	5.2	142.0	142.0	143.3
14	5.1	144.4	143.9	142.3
18	4.8	143.9	144.0	143.7
24	4.6	146.1	143.9	145.3
36	4.3	147.7	145.8	145.6

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 1
DYNAMIC FORCE: 7000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	.6	133.4	135.5	135.2
1	.8	134.0	137.3	138.1
2	.6	137.5	139.6	139.2
3	.6	138.8	139.6	139.9
4	.7	138.7	139.4	140.0
5	.5	139.8	140.4	142.0
6	.7	138.1	139.3	140.2
8	.7	139.8	139.1	138.9
10	.7	140.2	139.8	141.1
14	.7	141.7	141.6	140.5
18	.6	144.7	143.6	144.2
24	.6	143.4	143.6	143.9
36	.7	146.3	145.0	143.2

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 2
DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	.8	132.4	135.8	136.1
1	.8	131.9	134.1	134.5
2	.9	134.1	135.0	136.7
3	.8	135.7	136.6	138.0
4	.8	137.3	138.4	137.9
5	.8	138.1	137.7	137.9
6	.8	138.8	138.6	137.2
8	.8	137.5	135.6	139.1
10	.9	137.3	138.5	137.5
14	.9	139.8	139.9	139.2
18	.8	142.0	140.8	139.5
24	.9	142.1	141.6	139.5
36	.9	144.0	142.5	142.5

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 1
DYNAMIC FORCE: 7000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	4.3	129.7	132.8	133.6
1	3.8	131.1	135.1	134.9
2	3.8	132.6	135.1	136.6
3	3.8	134.0	135.6	138.0
4	3.8	134.9	135.1	135.6
5	3.7	134.8	135.5	136.5
6	3.7	134.2	137.0	139.0
8	3.5	138.7	139.2	138.8
10	3.4	140.1	140.0	140.7
14	3.4	142.1	142.0	140.3
18	3.5	140.9	141.7	142.4
24	3.2	142.5	143.0	142.3
36	3.1	143.1	142.4	141.5

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 2
DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	4.1	124.7	131.5	129.8
1	4.0	134.2	133.6	134.6
2	4.1	135.5	135.9	134.0
3	3.9	136.1	136.4	137.0
4	4.1	138.1	137.7	137.5
5	4.0	137.5	137.6	137.1
6	4.0	139.2	138.9	138.1
8	3.8	141.6	141.1	141.5
10	3.9	143.1	142.8	142.1
14	4.1	143.6	143.8	142.1
18	4.1	143.3	144.5	144.3
24	4.1	146.9	146.6	147.7
36	4.1	148.0	147.6	146.9

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 1
DYNAMIC FORCE: 7000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	5.4	132.2	135.5	136.5
1	5.0	135.2	137.4	137.1
2	4.9	136.6	138.3	139.3
3	4.8	137.6	140.0	139.8
4	4.7	139.4	140.3	139.3
5	4.6	140.3	140.2	139.1
6	4.4	140.3	141.4	141.5
8	4.0	138.9	139.4	138.6
10	3.8	138.7	139.2	138.7
14	4.0	143.7	143.9	141.2
18	4.2	143.4	142.9	142.1
24	4.1	145.1	144.3	144.2
36	4.2	146.1	144.7	143.3

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 2
DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-6"	0-8"	0-12"
0	5.1	131.8	134.7	136.4
1	5.0	136.8	137.7	139.0
2	5.3	139.3	140.3	140.9
3	5.4	142.8	142.3	142.6
4	5.4	144.0	142.3	143.1
5	5.3	143.7	142.9	142.6
6	5.3	145.0	142.5	142.1
8	5.5	145.9	143.7	143.7
10	5.3	144.7	142.7	143.0
14	5.1	146.3	144.0	144.5
18	5.0	147.0	144.4	145.4
24	5.1	147.9	145.4	146.5
36	5.0	148.1	146.8	146.0

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 3
DYNAMIC FORCE: 19500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.7	139.8	140.1	138.9
1	.6	139.2	137.3	140.7
2	.6	139.2	140.0	139.8
3	.5	138.1	140.7	140.6
4	.5	142.0	140.8	141.2
6	.7	142.2	139.8	142.5
8	.6	140.7	139.2	141.0
12	.6	142.5	141.9	141.8
18	.5	142.9	144.2	144.0
24	.6	144.2	144.3	143.7
36	.8	141.1	143.1	142.7

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 4
DYNAMIC FORCE: 25000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.5	138.8	138.7	137.1
1	.5	140.0	139.6	139.6
2	.7	138.9	139.1	140.0
3	.5	139.0	140.7	140.0
4	.5	140.2	140.0	137.1
6	.5	141.8	141.4	141.2
8	.6	141.6	141.3	141.0
12	.5	142.3	143.3	143.7
18	.6	145.3	143.9	143.9
24	.6	145.6	144.2	142.9
36	.4	147.1	146.9	146.0

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 3
DYNAMIC FORCE: 19500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.0	127.8	130.2	132.5
1	3.8	132.1	135.0	134.4
2	3.8	133.5	134.4	135.2
3	4.0	135.4	137.9	137.2
4	3.9	136.5	137.2	136.5
6	3.9	138.6	138.2	137.6
8	4.0	139.4	137.7	137.1
12	3.7	140.7	140.8	139.9
18	3.8	141.3	141.7	141.2
24	3.9	143.3	142.1	141.7
36	3.8	147.0	144.4	141.9

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 4
DYNAMIC FORCE: 25000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	3.7	132.2	133.8	134.1
1	3.6	132.4	134.3	136.7
2	3.8	132.8	135.7	137.8
3	3.8	136.0	137.3	138.3
4	3.9	137.3	137.4	138.0
6	3.7	139.7	140.1	139.0
8	3.7	141.1	141.5	139.8
12	3.6	139.8	139.3	140.9
18	3.5	143.8	143.6	141.5
24	3.7	142.3	143.2	142.7
36	3.7	142.6	143.2	142.3

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 3
DYNAMIC FORCE: 19500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.9	132.9	135.7	134.8
1	4.7	133.7	134.7	133.7
2	4.8	136.7	137.0	137.0
3	4.9	139.1	139.2	139.0
4	4.8	137.9	138.6	138.0
6	4.7	139.7	140.9	141.0
8	4.4	140.5	141.6	142.4
12	4.2	143.2	144.1	143.8
18	4.8	143.4	143.2	142.1
24	4.3	144.9	145.2	142.9
36	4.2	147.8	147.9	147.5

ROLLER: HYSTER 625A FREQUENCY: 1800
AMPLITUDE: 4
DYNAMIC FORCE: 25000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.0	132.3	133.5	135.0
1	4.7	135.6	137.1	138.0
2	4.6	135.5	137.4	138.2
3	4.5	135.6	136.6	137.0
4	4.2	138.5	137.6	137.2
6	4.6	139.8	139.7	139.7
8	4.7	139.6	140.7	140.6
12	4.1	142.6	142.5	142.3
18	4.6	144.5	143.4	141.7
24	4.5	146.0	143.8	143.3
36	4.5	143.8	141.5	143.7

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H FREQUENCY: 2100 AMPLITUDE: 2 DYNAMIC FORCE: 18000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.8	130.5	130.4	127.6
1	.8	133.7	132.4	133.0
2	.7	134.8	135.3	133.0
3	.8	136.1	133.4	136.1
4	.8	133.7	136.2	135.7
5	.8	134.3	132.3	134.1
6	.8	134.1	138.0	137.1
8	.8	137.6	138.6	138.6
10	.8	140.1	140.1	139.2
14	.8	141.9	139.9	140.2
18	.8	142.8	140.6	139.1
24	.8	143.8	141.5	141.3
30	.8	145.2	142.6	142.0

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: HYSTER 625H FREQUENCY: 2400 AMPLITUDE: 2 DYNAMIC FORCE: 23500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.5	142.0	143.3	143.1
1	.4	142.3	142.1	141.4
2	.3	144.7	144.1	144.8
3	.3	141.7	142.9	142.3
4	.3	145.1	145.8	145.4
5	.5	144.2	144.9	144.7
6	.5	143.7	145.2	145.4
8	.6	143.7	145.2	145.4
10	.5	146.9	143.7	142.9
14	.6	144.3	145.4	144.6
18	.5	146.6	146.7	147.2
24	.5	149.2	149.7	148.9
30	.3	150.9	150.1	149.2

ROLLER: HYSTER 625H FREQUENCY: 2100 AMPLITUDE: 2 DYNAMIC FORCE: 18000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.1	129.0	130.4	131.4
1	3.8	134.1	134.8	136.1
2	4.0	135.9	137.3	136.9
3	4.0	138.7	138.5	136.8
4	4.0	139.5	140.0	140.2
5	4.0	140.3	140.4	140.2
6	4.1	140.6	141.3	140.8
8	4.1	143.3	143.0	143.2
10	3.8	144.7	143.1	143.8
14	4.0	146.0	145.3	145.0
18	4.2	146.9	145.9	145.7
24	4.2	147.3	146.2	145.6
30	4.2	146.0	145.5	147.4

ROLLER: HYSTER 625H FREQUENCY: 2400 AMPLITUDE: 2 DYNAMIC FORCE: 23500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.6	137.4	138.3	136.6
1	4.1	137.8	139.9	140.0
2	4.0	138.0	139.0	137.2
3	4.1	137.3	139.1	139.9
4	4.2	139.1	140.3	139.0
5	4.2	140.4	140.3	141.0
6	4.1	140.6	140.8	141.3
8	4.2	142.7	143.3	144.3
10	4.0	144.2	145.1	143.2
14	4.0	145.6	144.7	145.1
18	4.1	144.9	145.0	144.4
24	4.0	145.3	144.8	145.1
30	4.1	147.1	144.4	143.5

ROLLER: HYSTER 625H FREQUENCY: 2100 AMPLITUDE: 2 DYNAMIC FORCE: 18000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.9	136.5	137.2	137.6
1	5.6	140.1	140.9	140.8
2	5.6	143.3	140.8	141.3
3	5.6	142.5	140.5	143.4
4	5.5	143.6	142.4	143.2
5	5.4	143.0	142.4	143.6
6	5.5	143.9	143.4	142.4
8	5.2	144.2	143.0	142.4
10	5.8	144.0	142.2	143.0
14	5.9	145.0	143.1	141.2
18	5.8	144.5	143.4	143.4
24	5.6	146.8	145.6	144.5
30	5.8	146.8	145.0	145.0

ROLLER: HYSTER 625H FREQUENCY: 2400 AMPLITUDE: 2 DYNAMIC FORCE: 23500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.4	134.9	136.6	137.6
1	5.3	136.9	138.3	139.2
2	5.3	139.3	140.2	138.1
3	5.1	138.0	139.1	139.9
4	5.3	141.3	140.8	141.4
5	5.6	142.2	141.2	141.3
6	5.9	142.5	142.1	142.6
8	6.1	143.7	143.8	144.5
10	5.9	144.4	143.7	144.3
14	6.0	145.0	143.4	144.0
18	5.9	145.9	144.1	142.7
24	5.1	141.5	143.5	144.7
36	4.9	149.0	148.2	148.2

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 404B   FREQUENCY: 1200   AMPLITUDE: High   DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.6	138.2	139.9	139.7
1	.4	140.1	139.3	141.4
2	.5	140.9	140.8	142.0
3	.5	140.4	141.3	141.1
4	.4	140.9	140.9	141.6
5	.4	141.9	141.2	142.3
6	.5	142.7	141.5	141.4
8	.4	144.1	145.0	144.1
10	.4	143.3	144.0	144.2
14	.4	144.7	144.5	145.1
18	.6	144.0	144.9	145.1
24	.3	145.3	146.2	145.4

ROLLER: RAYGO 404B   FREQUENCY: 1200   AMPLITUDE: High   DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.6	137.5	137.7	137.4
1	4.3	138.2	139.5	140.5
2	4.3	139.8	139.4	139.5
3	4.3	139.2	140.5	141.3
4	4.0	140.4	139.8	139.9
5	3.8	139.4	141.3	142.1
6	3.9	139.2	140.9	142.1
8	3.8	142.6	143.6	143.3
10	3.9	142.9	144.3	143.7
14	3.7	143.8	144.5	144.9
18	3.7	144.9	144.9	145.7
24	3.6	144.2	144.2	145.0

ROLLER: RAYGO 404B   FREQUENCY: 1200   AMPLITUDE: High   DYNAMIC FORCE: 13500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	7.7	140.5	140.1	139.9
1	6.4	139.9	140.8	139.9
2	6.3	142.4	142.8	143.9
3	6.4	144.3	144.8	144.9
4	5.9	145.3	145.5	144.2
5	5.7	144.2	145.5	144.9
6	5.2	144.8	144.4	145.7
8	4.9	146.9	146.1	145.3
10	4.5	147.8	147.0	145.3
14	4.1	144.8	145.2	146.8
18	3.9	144.4	145.0	147.2
24	4.0	146.6	146.2	147.1

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 404B   FREQUENCY: 1700   AMPLITUDE: High   DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.6	136.2	138.6	139.0
1	.4	138.9	138.9	140.2
2	.4	141.4	141.2	141.9
3	.5	141.4	141.6	142.0
4	.4	143.3	143.1	144.9
5	.4	142.3	142.6	140.6
7	.4	143.5	143.0	142.9
9	.4	143.5	144.4	144.1
13	.4	142.9	143.5	143.7
17	.5	144.7	145.3	145.3
23	.4	147.0	146.7	146.0

ROLLER: RAYGO 404B   FREQUENCY: 1700   AMPLITUDE: High   DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.4	131.7	133.1	136.2
1	4.3	135.2	136.4	137.5
2	4.0	136.2	136.1	139.0
3	4.1	137.9	139.0	139.0
4	4.0	138.6	140.0	141.6
5	3.9	139.3	139.2	142.3
7	3.9	138.9	139.4	141.5
9	3.6	139.2	141.3	143.9
13	3.7	140.4	143.2	144.7
17	3.7	142.7	144.8	145.0
23	3.8	142.5	143.0	145.0

ROLLER: RAYGO 404B   FREQUENCY: 1700   AMPLITUDE: High   DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.9	129.6	132.2	131.5
1	5.2	131.2	133.1	132.0
2	4.8	135.7	134.8	136.0
3	4.7	136.1	137.1	136.9
4	4.5	136.0	138.1	139.2
5	4.3	138.3	139.4	141.7
7	4.2	141.1	141.1	141.1
9	4.5	143.4	143.8	143.3
13	4.7	142.9	142.4	142.6
17	4.8	143.5	142.9	143.3
23	4.2	141.4	143.3	142.4

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 404H — FREQUENCY: 2300 — AMPLITUDE: Low — DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.4	137.5	136.6	139.6
1	.4	135.0	139.9	140.3
2	.5	139.3	138.5	138.1
3	.3	142.1	141.4	140.9
4	.3	143.4	143.5	145.3
5	.4	144.0	143.8	144.1
6	.3	142.0	143.4	142.7
8	.3	142.1	143.9	144.6
10	.4	143.4	144.3	142.9
14	.3	143.1	145.0	145.2
18	.4	145.9	145.2	145.5
24	.3	147.1	146.2	147.2
36	.4	145.4	146.5	148.4

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 400A — FREQUENCY: 1200 — AMPLITUDE: N/A — DYNAMIC FORCE: 17500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.5	136.6	134.7	136.0
1	.4	136.5	137.8	137.1
2	.4	138.4	138.8	135.0
3	.4	138.8	139.2	142.9
4	.6	139.7	140.9	141.6
5	.3	140.7	142.1	142.6
6	.4	140.5	141.8	142.5
8	.6	140.7	142.2	143.1
10	.4	142.0	143.8	143.8
14	.6	145.2	144.6	143.7
18	.8	144.2	143.5	145.7
24	.4	145.8	144.5	146.6
36	.3	146.2	144.8	144.8
48	.5	148.7	148.3	149.0

ROLLER: RAYGO 404H — FREQUENCY: 2300 — AMPLITUDE: Low — DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.9	130.3	131.2	132.2
1	4.5	134.1	136.7	136.4
2	4.4	137.3	137.8	137.7
3	4.4	138.2	139.0	137.2
4	4.5	138.7	139.2	138.8
5	4.5	139.9	139.4	138.7
6	4.4	142.0	141.3	140.0
8	4.3	140.6	141.3	141.2
10	4.1	140.5	141.3	141.4
14	4.2	141.8	140.8	143.1
18	4.2	142.6	143.6	143.0
24	4.2	145.9	144.0	145.3
36	3.8	145.4	146.1	145.1

ROLLER: RAYGO 400A — FREQUENCY: 1200 — AMPLITUDE: N/A — DYNAMIC FORCE: 17500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.1	133.2	135.5	136.1
1	5.0	133.7	135.1	134.2
2	4.8	138.3	138.6	137.8
3	4.8	138.2	139.1	139.4
4	5.2	141.6	141.0	139.8
5	5.2	141.1	140.2	141.1
6	5.7	141.0	140.6	141.8
8	4.4	142.6	142.4	143.3
10	4.8	141.4	143.4	143.4
14	4.4	144.1	146.4	143.9
18	4.5	144.0	144.0	144.8
24	3.7	144.5	145.3	144.3
36	3.7	147.2	147.9	147.8
48	3.8	148.1	147.3	147.6

ROLLER: RAYGO 404H — FREQUENCY: 2300 — AMPLITUDE: Low — DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.5	130.4	132.3	133.6
1	5.5	138.3	138.8	137.8
2	5.9	139.7	139.1	138.9
3	5.8	141.6	140.2	139.5
4	6.0	140.3	138.6	138.7
5	6.1	140.3	139.6	140.5
6	5.9	140.4	140.5	140.5
8	5.9	140.3	140.1	141.1
10	5.6	143.8	141.6	142.4
14	5.1	145.8	141.8	142.4
18	5.4	145.0	143.3	142.5
24	4.9	145.7	142.3	143.6
36	4.8	147.5	146.9	147.9

ROLLER: RAYGO 400A — FREQUENCY: 1200 — AMPLITUDE: N/A — DYNAMIC FORCE: 17500

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.9	131.7	134.5	136.5
1	5.4	133.9	136.2	137.1
2	5.2	138.2	138.5	138.4
3	5.5	138.8	139.3	140.8
4	5.8	139.7	140.7	140.2
5	5.8	140.1	140.3	141.3
6	5.6	141.1	141.5	141.0
8	5.2	141.2	141.6	142.3
10	5.4	141.8	141.7	142.1
14	5.6	142.7	142.9	142.8
18	5.3	143.4	143.2	142.7
24	5.0	146.1	144.4	144.1
36	4.6	148.3	147.8	147.8
48	4.3	149.5	147.3	146.6

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 600A   FREQUENCY: 1500
AMPLITUDE: N/A
DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.6	132.0	134.3	135.0
1	.6	137.2	135.4	133.8
2	.7	134.3	135.8	135.6
3	.7	135.5	136.7	137.7
4	.7	138.5	136.8	135.3
5	.6	137.1	138.3	138.6
6	.6	138.3	138.8	138.7
8	.7	140.2	139.3	139.0
10	.7	141.0	140.6	140.8
14	.7	141.6	142.0	140.8
18	.7	141.8	141.6	141.4
24	.7	143.2	140.6	139.9
36	.7	143.6	143.3	143.9

ROLLER: RAYGO 600A   FREQUENCY: 1500
AMPLITUDE: N/A
DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.4	131.6	132.7	133.3
1	4.4	134.4	136.3	137.9
2	4.4	137.3	138.0	138.5
3	4.3	139.8	139.1	138.4
4	4.2	140.2	140.0	137.9
5	4.1	142.2	141.2	140.7
6	4.1	142.9	140.7	142.0
8	4.4	142.6	141.1	140.1
10	4.3	142.3	141.6	140.9
14	4.3	143.1	142.0	142.3
18	4.2	143.2	143.6	143.6
24	3.9	145.5	146.2	146.0
36	3.8	145.9	146.0	145.0

ROLLER: RAYGO 600A   FREQUENCY: 1500
AMPLITUDE: N/A
DYNAMIC FORCE: 27000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.7	134.0	134.4	135.3
1	5.6	135.3	137.4	138.5
2	5.8	139.2	139.6	139.3
3	5.9	140.9	140.2	140.4
4	5.9	142.9	141.5	141.2
5	5.5	144.1	141.9	141.7
6	5.5	144.3	142.1	141.9
8	5.6	145.1	143.3	143.2
10	5.4	145.4	144.2	144.5
14	5.2	146.3	143.8	143.7
18	5.0	146.3	145.9	146.5
24	5.0	146.7	145.5	144.8
36	5.3	147.0	145.8	145.1

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 510A   FREQUENCY: 1200
AMPLITUDE: N/A
DYNAMIC FORCE: 29000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.4	137.8	136.7	136.3
1	.5	139.5	138.1	138.5
2	.5	139.9	139.3	139.5
3	.7	140.5	140.1	140.4
4	.4	140.3	142.2	141.9
5	.4	141.3	141.9	142.3
6	.6	141.4	142.0	142.5
8	.6	144.2	144.2	142.4
10	.6	142.3	144.1	143.9
14	.4	142.8	145.6	146.0
18	.7	146.2	144.7	144.7
24	.5	145.7	147.4	146.0
36	.4	145.1	146.2	147.1
48	.5	143.7	145.4	146.6

ROLLER: RAYGO 510A   FREQUENCY: 1200
AMPLITUDE: N/A
DYNAMIC FORCE: 29000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	5.3	133.1	135.0	135.7
1	4.6	135.5	138.3	137.3
2	4.6	137.9	139.1	139.2
3	4.8	139.7	139.5	140.1
4	4.6	139.8	141.7	141.9
5	4.7	141.2	141.6	142.2
6	4.9	141.3	141.5	143.0
8	4.7	143.3	142.5	143.1
10	4.9	142.7	143.4	144.2
14	4.9	144.4	143.8	144.9
18	4.9	145.6	143.4	144.0
24	4.8	146.4	145.4	145.1
36	4.0	149.8	148.4	147.6
48	4.5	150.4	148.1	147.6

ROLLER: RAYGO 510A   FREQUENCY: 1200
AMPLITUDE: N/A
DYNAMIC FORCE: 29000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	6.8	136.9	136.8	137.5
1	6.2	138.1	138.1	139.6
2	6.0	139.2	138.7	139.2
3	6.1	139.9	138.7	140.0
4	5.9	140.7	139.6	139.7
5	5.9	142.1	141.8	142.2
6	5.5	142.4	141.3	142.5
8	6.1	142.2	141.3	142.9
10	6.6	142.6	140.7	141.1
14	6.5	143.6	141.3	142.4
18	5.6	145.5	143.4	143.9
24	5.5	147.6	144.7	143.5
36	5.5	149.7	146.7	147.5
48	5.4	149.2	148.2	145.7

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 510A FREQUENCY: 1200 AMPLITUDE: N/A DYNAMIC FORCE: 29000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	2.8	129.1	132.7	133.9
1	2.7	135.3	136.8	135.0
2	2.7	135.1	136.0	136.6
3	2.5	138.1	137.0	138.2
4	2.8	137.3	137.6	138.3
5	3.0	138.1	137.9	139.8
6	2.8	139.5	139.9	139.9
8	2.8	141.1	140.2	140.2
10	2.6	141.8	141.4	142.5
14	2.5	143.5	142.7	142.1
18	2.6	144.7	144.7	143.5
24	2.6	145.1	145.2	148.9
36	2.7	146.2	145.8	145.8

ROLLER: RAYGO 510A FREQUENCY: 1200 AMPLITUDE: N/A DYNAMIC FORCE: 29000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	3.2	124.7	131.0	132.5
1	2.9	133.8	133.4	135.4
2	2.9	137.8	136.1	136.8
3	2.9	136.1	138.9	138.2
4	2.8	139.0	139.7	139.6
5	3.0	137.8	138.1	140.2
6	2.9	139.6	140.0	140.5
8	2.9	140.9	141.2	142.9
10	3.1	142.4	142.5	141.4
14	2.9	143.8	144.9	146.3
18	2.9	145.3	145.7	145.7
24	2.8	144.7	146.6	145.4
36	3.0	146.3	146.5	145.4

NUCLEAR MOISTURE-DENSITY DATA

ROLLER: RAYGO 510A FREQUENCY: 1500 AMPLITUDE: N/A DYNAMIC FORCE: 45000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	.7	132.6	133.0	132.6
1	.6	136.0	136.8	137.2
2	.6	135.6	137.9	137.8
3	.6	139.5	138.5	138.8
4	.6	139.0	138.0	139.5
5	.6	136.9	138.5	138.3
6	.5	138.2	139.7	139.5
8	.5	139.6	139.4	141.3
10	.6	140.1	140.7	140.6
14	.6	142.1	143.0	144.8
18	.5	142.3	142.9	144.7
24	.7	142.1	143.0	144.9
36	.5	144.6	146.0	145.2

ROLLER: RAYGO 510A FREQUENCY: 1500 AMPLITUDE: N/A DYNAMIC FORCE: 45000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	4.7	130.3	134.6	135.8
1	4.3	137.7	138.6	139.4
2	4.2	139.9	139.9	140.2
3	4.3	139.9	140.9	141.8
4	4.3	142.2	142.2	142.3
5	4.1	142.0	142.4	143.1
6	4.1	141.5	143.2	142.6
8	4.3	142.2	141.3	142.1
10	4.3	143.0	142.7	143.6
14	4.1	145.3	144.5	144.2
18	4.4	144.8	144.3	144.0
24	4.5	145.4	145.5	145.8
36	4.6	146.3	145.5	146.0

ROLLER: RAYGO 510A FREQUENCY: 1500 AMPLITUDE: N/A DYNAMIC FORCE: 45000

PASS #	MOISTURE CONTENT	AVERAGE DRY DENSITY 0-4"	0-8"	0-12"
0	6.5	138.6	139.1	139.6
1	6.5	141.0	139.5	139.8
2	6.3	140.5	139.2	140.0
3	6.0	141.2	140.1	140.1
4	6.1	142.3	140.6	140.8
5	6.8	141.7	141.5	139.1
6	7.3	140.7	140.0	139.0
8	6.9	142.9	140.6	141.1
10	6.4	143.5	141.8	141.9
14	5.7	145.5	143.9	143.8
18	5.9	146.7	144.4	144.0
24	5.5	147.4	142.7	145.7
36	5.7	149.2	146.1	146.8

NUCLEAR MOISTURE-DENSITY DATA

DEEP LIFT TEST

ROLLER: HYSTER 625B   FREQUENCY: 1800
AMPLITUDE: 4
DYNAMIC FORCE: 25000

PASS #	CONTENT	DEPTH OF MEASUREMENT, INCHES	AVERAGE DRY DENSITY
0	0.7	0 - 4	131.3
		0 - 8	132.0
		0 - 12	133.4
4	0.7	0 - 4	136.7
		0 - 8	136.7
		0 - 12	138.1
		12 - 16	128.4
		12 - 20	127.9
		12 - 24	129.0
		24 - 28	122.1
		24 - 32	124.9
6	0.7	0 - 4	137.1
		0 - 8	139.0
		0 - 12	141.5
8	0.8	0 - 4	140.2
		0 - 8	138.0
		0 - 12	137.3
		12 - 16	127.9
		12 - 20	128.7
		12 - 24	131.0
		24 - 28	121.3
		24 - 32	123.8
		24 - 36	124.7
12	0.7	0 - 4	141.3
		0 - 8	140.8
		0 - 12	141.3
		12 - 16	129.5
		12 - 20	129.7
		12 - 24	131.7
		24 - 28	122.4
		24 - 32	125.1
		24 - 36	124.1
24	0.6	0 - 4	140.0
		0 - 8	142.1
		0 - 12	143.2
36	0.7	0 - 4	138.6
		0 - 8	140.9
		0 - 12	140.6
		12 - 16	130.0
		12 - 20	128.5
		12 - 24	127.7
		24 - 28	124.8
		24 - 32	124.4
		24 - 36	125.4

NUCLEAR MOISTURE-DENSITY DATA

DEEP LIFT TEST

ROLLER: HYSTER 625B   FREQUENCY: 1800
AMPLITUDE: 4
DYNAMIC FORCE: 25000

PASS #	CONTENT	DEPTH OF MEASUREMENT, INCHES	AVERAGE DRY DENSITY
0	4.8	0 - 4	132.3
		0 - 8	134.2
		0 - 12	134.4
4	4.8	0 - 4	139.6
		0 - 8	139.4
		0 - 12	140.2
		12 - 16	131.8
		12 - 20	135.1
		12 - 24	135.9
		24 - 28	132.8
		24 - 32	134.6
		24 - 36	135.3
6	4.7	0 - 4	140.7
		0 - 8	141.1
		0 - 12	140.9
8	4.7	0 - 4	138.9
		0 - 8	139.4
		0 - 12	138.9
		12 - 16	129.1
		12 - 20	130.8
		12 - 24	133.7
		24 - 28	132.0
		24 - 32	134.0
		24 - 36	133.3
12	4.6	0 - 4	143.8
		0 - 8	143.4
		0 - 12	143.9
		12 - 16	131.2
		12 - 20	135.2
		12 - 24	136.1
		24 - 28	127.6
		24 - 32	130.1
		24 - 36	130.0
24	4.8	0 - 4	142.2
		0 - 8	143.1
		0 - 12	142.8
36	4.8	0 - 4	144.2
		0 - 8	142.6
		0 - 12	142.3
		12 - 16	131.0
		12 - 20	135.6
		12 - 24	134.7
		24 - 28	125.2
		24 - 32	127.0
		24 - 36	127.9

NUCLEAR MOISTURE-DENSITY DATA

DEEP LIFT TEST

ROLLER: RAYGO 510A **FREQUENCY:** 1200
DYNAMIC FORCE: 29000

PASS #	CONTENT	DEPTH OF MEASUREMENT, INCHES	AVERAGE DRY DENSITY
0	0.6	0 - 4	137.8
		0 - 8	138.9
		0 - 12	139.1
4	0.8	0 - 4	137.5
		0 - 8	138.6
		0 - 12	138.8
		12 - 16	128.5
		12 - 20	129.5
		12 - 24	131.9
		24 - 28	122.6
		24 - 32	122.7
		24 - 36	124.5
6	0.6	0 - 4	138.0
		0 - 8	139.0
		0 - 12	139.4
8	0.8	0 - 4	138.0
		0 - 8	141.2
		0 - 12	142.3
		12 - 16	129.4
		12 - 20	131.1
		12 - 24	129.7
		24 - 28	122.4
		24 - 32	125.2
		24 - 36	125.9
12	0.7	0 - 4	142.2
		0 - 8	142.4
		0 - 12	142.0
		12 - 16	131.6
		12 - 20	133.0
		12 - 24	132.8
		24 - 28	125.5
		24 - 32	126.2
		24 - 36	126.6
24	0.7	0 - 4	140.4
		0 - 8	141.2
		0 - 12	144.1
36	0.8	0 - 4	145.0
		0 - 8	145.8
		0 - 12	145.3
		12 - 16	133.1
		12 - 20	133.1
		12 - 24	134.7
		24 - 28	125.2
		24 - 32	128.9
		24 - 36	130.3

NUCLEAR MOISTURE-DENSITY DATA

DEEP LIFT TEST

ROLLER: RAYGO 510A **FREQUENCY:** 1200
DYNAMIC FORCE: 29000

PASS #	CONTENT	DEPTH OF MEASUREMENT, INCHES	AVERAGE DRY DENSITY
0	4.5	0 - 4	131.2
		0 - 8	133.1
		0 - 12	136.2
4	4.8	0 - 4	141.7
		0 - 8	140.2
		0 - 12	140.7
		12 - 16	127.4
		12 - 20	130.5
		12 - 24	131.2
		24 - 28	125.7
		24 - 32	127.0
		24 - 36	128.1
6	4.6	0 - 4	140.2
		0 - 8	140.5
		0 - 12	140.4
8	4.6	0 - 4	142.4
		0 - 8	141.5
		0 - 12	142.8
		12 - 16	133.2
		12 - 20	135.6
		12 - 24	135.9
		24 - 28	126.7
		24 - 32	130.4
		24 - 36	132.5
12	4.6	0 - 4	143.6
		0 - 8	142.2
		0 - 12	142.8
		12 - 16	131.5
		12 - 20	135.0
		12 - 24	133.3
		24 - 28	128.4
		24 - 32	128.5
		24 - 36	129.9
24	4.4	0 - 4	145.9
		0 - 8	144.8
		0 - 12	145.0
36	4.5	0 - 4	147.2
		0 - 8	145.4
		0 - 12	145.4
		12 - 16	134.7
		12 - 20	136.6
		12 - 24	135.4
		24 - 28	127.8
		24 - 32	126.3
		24 - 36	130.0

INITIAL DISTRIBUTION

DTIC-DDA-2	12
HQ AFSC/SDNE	1
HQ AFSC/DE	1
HQ USAFE/DEX	1
293rd Engr Combat Battalion	1
USAFTAWC/THL	1
AFATL/DLODL (Tech Library)	1
US Navy CEL	1
HQ ATC/DE	1
HQ MAC/DE	1
HQ AFESC/TST	1
HQ AFESC/DEO	1
USAE WESGF	1
HQ USAF/RDPX	1
EOARD/LNS	1
HQ PACAF/DE	1
NAVEODFAC	1
USA MERDC/DRDME	1
HQ TAC/DE	1
AUL/LSE 71-249	1
HQ SAC/DE	1
HQ AFLC/DEMG	1
AFISC/IGQ	1
WRALC/MMIICA3	1
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